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AIRBORNE FIBER OPTICS MANUFACTURING TECHNOLOGY. AIRCRAFT INSTAL--ETC(U)

OCT 78 G KOSMOS, R A GREENWELL

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This report is taken, in whole or in part, from contributions of the aforementioned personnel.

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Manufacturing processes are being developed for installation of optical fiber harnesses and "stand alone" links on military aircraft. Fabrication and installation plans and procedures are being developed and a routing analysis is being performed to provide a basis for installation of fiber optics in military aircraft. A life cycle cost analysis of the optical fiber harness indicates apparent economic advantages.

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OBJECTIVE

To develop installation processes and procedures for the incorporation of fiber optic interconnect systems aboard military aircraft.

RESULTS

1. Two fiber optic interconnects were designed for installation on the E-3A aircraft. The first was a 7-connector audio cable located in the upper bay. This harness utilizes single fiber, fiber bundle, and conventional wire cable and requires 56 terminations. The second cable, designated the "stand-alone link," is a 4-conductor, 2-section cable routed from the lower bay, over the wing stub, out through a pressure seal into the wheel well area, and onto the left landing gear main strut.

2. Components for both cables were selected and are in final pricing by vendors.

3. Fabrication and installation plans and procedures were developed and written to provide the necessary technology to accomplish these tasks during the second phase of the program.

4. Engineering drawings were prepared to support all design, fabrication, and installation activities.

5. A routing analysis was developed to provide a basis for future applications of fiber optics in military aircraft.

6. A life-cycle cost analysis of the optical cable was completed. It is apparent that weight and size reductions of fiber optics offer economic advantages. It is possible to increase the E-3A sortie time by 2.5 percent, which can be equated to a reduction of fleet size by 1.5 aircraft. The reliability of fiber optic interconnect systems appears to be equivalent to wire interconnect systems. It appears easier to install, remove and/or replace optical fibers. Optical fiber interconnect systems are also simpler to test. Spares, repair parts, materials, and special support/test equipment add to initial costs, as does almost any new technology, but the impact is minor. With simpler equipment and techniques there may be a long-term savings potential. Overall costs and benefits of fiber optics appear to surpass the E-3A wire interconnect configurations.

CONTENTS

INTRODUCTION

The objective of this work is to establish manufacturing methods in industry to assure the ability to install, on a production basis, fiber optic interconnect systems aboard military aircraft. This report contains the information gained through the first phase of a four-phase contract (N00123-78-C-0193) with Boeing Aerospace Corporation, Seattle, Washington.

BACKGROUND

It has been demonstrated in the A-7 Airborne Light Optical Fiber Technology (ALOFT) program that fiber optics can be successfully used on military aircraft. The many advantages of a multiplexed, fiber optic data interface – such as immunity to EMI (electromagnetic interference), EMP (electromagnetic pulse), and lightning strikes; reduced systems weight; and reduced complexity in external harnesses and connectors, resulting in improved reliability and maintainability – have also been demonstrated. Before fiber optics can be used on a production aircraft, installation practices and procedures must be established for high volume, low cost, fiber optic interconnects. By the development or improvement of installation processes, techniques, and equipment by the contractor (Boeing Aerospace), this work is intended to develop an industry source for the timely, reliable, and economical assembly of the required fiber optic interconnects.

SCOPE

As fiber optics has progressed from research and development to feasibility demonstrations, it has become apparent that planning for high volume production of fiber optic components is necessary. Questions of production compatibility, applicability, and cost are addressed under this contract in order to identify and correct problems associated with the installation of fiber optics aboard military aircraft. Two major requirements have been undertaken in this contract: (1) the fabrication and installation of fiber optic harnesses; and (2) the fabrication and installation of "stand-alone links." Present electrical harnesses conduct both electrical signal and power. Fiber optic harnesses developed under this contract shall conduct optical signals and electrical power and shall be a one-for-one replacement of the electrical harness counterpart. The stand-alone link accounts for retrofit applications for which no fiber optic harness is required – just stand-alone links. Associated with the two major requirements is the development of assembly methods and installation specifications for the incorporation of the harnesses and stand-alone links aboard a Boeing military-type surveillance aircraft. The assembly methods installation specifications, as well as the identification of routing techniques, support test equipment, field repair techniques and procedures, and a detailed cost analysis between the fiber optic cost and the original wire interconnect cost will be verified on a full-scale production mock-up.

DELIVERABLES

The Phase I deliverables are:

- Preliminary Harness Design
  Preliminary Stand-Alone Link Design
- Fabrication and Installation Procedures
  Fiber Optics Rack Integration Harness, and Stand-Alone Link
- Preliminary Installation Procedure (Harness and Link)
- Routing Techniques
- Preliminary Cost Analysis Report

SUMMARY OF TECHNICAL WORK

The following Technical Summary is a digest of the more in-depth work conducted by the contractor during Phase I.

COMPONENT SELECTION

Major components selected for the Phase I Link Designs (stand-alone link and harness) include four 4-terminal connectors and the fiber optics cable for the link and seven (three 20-terminal and four 4-terminal) connectors plus fiber bundle cable, single-fiber cable, and conventional wire for the harness. Relatively minor items, including outer braid, tie materials, clamps, etc., are commonly shop stock and will be selected as required on the program.

As indicated in appendix A, Harness/Link Designs, the connectors for the program have been chosen from three different vendors so that a broad base of connector types may be evaluated as to cost, availability, termination ease, suitability for manufacturing and assembly processes, optical properties, and environmental capability. The connector chosen for the stand-alone link is the Amphenol 4-terminal unit which is compatible with the heavy-duty fiber optics 46-mil bundle cable requested by the contractor for this application. The connectors chosen for the harness include three 20-terminal Hughes C-21 rectangular jack-screw units capable of mating single-fiber, 46-mil fiber bundle (medium duty) and conventional wire. The four 4-terminal connectors for the harness will be ITT Cannon MIL-C-83723(PV) type, of which three will be suitable for fiber bundle use and one suitable for single-fiber applications. All connectors for both links will be supplied with suitable inserts and backshells. All connector assembly will be done at Boeing using standard polishing and terminating equipment plus special crimping and assembly tools peculiar to each of the connectors and cables. All connectors chosen will meet the contract requirements for aircraft environments.

The cables chosen for the links will be of four types: single fiber, heavy-duty fiber bundle, medium-duty fiber bundle, and standard 22-gauge twisted pair. The heavy-duty and medium-duty 46-mil fiber bundle cable was quoted by three manufacturers and will be purchased from one of the three (Galileo, Times, or Valtec) based upon final pricing during the next phase of the contract. The single-fiber cable chosen (to be used in the harness) will be of the large core type (8–10 mil core diameter) and will be Galileo type 3000 LC. This particular cable provides much better optical properties with respect to coupling losses and can be terminated with reasonable ease using any of the connector types chosen for the contract. The conventional wire will be drawn from stock and was therefore not put out for bid.

SELECTION OF MILITARY TYPE AIRCRAFT AND CONVENTIONAL HARNESS

A contractural requirement was the selection of a suitable airframe or mock-up for the fiber optic interconnect installation. The airframe or mock-up was to be limited to:

a. high performance fighter type aircraft,

b. military surveillance aircraft, or

c. other aircraft which must perform in the military environment.

For this program, the aircraft selected was the E-3A, for which a full-scale, Class III mock-up is available.

A complex communication system cable harness was selected from the E-3A to be the conventional harness that will be replaced by the fiber optic interconnect system. Details of the harness are given in appendix A.

PRELIMINARY INSTALLATION PLAN

The installation plan developed for use in this program is based upon the harness/link designs discussed in appendix A and upon the detailed installation procedure to provide specific information on each of the steps involved in the assembly and installation process. This installation plan is described in appendix B. The installation plan details the routing of the cable through each of the sections of the airplane and is supported by production illustration (P.I.) drawings which illustrate all support points for each of the cables, plus information on the pressure hull penetration, and the conduit necessary for protection from the landing gear environment (in the case of the stand-alone link). Installation methods are based primarily upon present methods used for conventional cable utilizing special handling procedures developed for small diameter coax cable and modified for the fiber optics cable.

Particular problems expected during installation include:

a. Adequate protection of terminations during the pull.

b. Protection against shock.

c. Protection against strain.

d. Observance of minimum bend radius criteria.

Problems expected during the harness assembly operation include:

a. Proper termination and polishing.

b. Second end assembly (should this be done at the form board or back at the primary polishing/termination station?)

c. Protection of terminations during the assembly sequence.

d. Development of lower cost marking and identification methods compatible with the Tefzel cable covering.

A generalized installation plan is given in appendix C.

FIBER OPTICS HARNESS/LINK DESIGNS

The two fiber optic interconnects are the stand-alone link and the seven-connector communications harness. The harness design is based upon the E-3A W1870 harness as discussed in the Boeing proposal. This harness originally contained 114 terminations of wires, jumpers, shields, and grounds which was reduced to 56 terminations of fiber optics cables, wires, and grounds in the fiber-optics/conventional-wire hybrid version, while still meeting the EMI and TEMPEST requirements of the original harness. The connectors and cables chosen for this harness and the link are as described in the component selection section and appendix A. The link design was based upon discussions held with the contractor and the contractual requirements of a point-to-point digital data link for an add-on system containing four fiber bundle cables of the heavy duty type. The routing of this cable was intentionally chosen to include passage through a pressure seal, a midpoint disconnect, and exposure to the environmental extremes (such as weather, flying rocks, and hydraulic fluid) found in the landing gear area. This routing will demand that the routing procedures and the cable construction and protection (conduit) include not just the minimum needed to install a cable but provision for a full measure of procedures designed to provide maximum fiber optics cable utilization. It is believed that this goal has been met.

ROUTING TECHNIQUES

An analysis of the routing techniques for fiber optic interconnects was made using the routing criteria of conventional wire as a starting point. An assessment was made of hazardous/sensitive areas on the aircraft and the ability of fiber optics to be routed through these areas. Coupled with this analysis are the environmental constraints placed on the fiber optic system (per MIL-E-5400P requirements) and the ability of the fiber optic components to withstand this environment.

It was determined that, with proper attention to the cladding material, fiber optics can be routed through any hazardous or sensitive area within a military-type airframe. However, some areas exist which will prohibit either the detection or sourcing of fiber optic information. This is due to current limitation on the lifetime of sources/detectors as a function of temperature. Similarly, sources/detectors, and to some degree fibers themselves, are sensitive to radiation effects, although to varying degrees. Technology trends, however, show a gradual improvement in component parameters by which it will become feasible (in the mid-1980's) to route fiber optics into, out of, and through all areas of the aircraft.

A detailed discussion of routing techniques is given in appendix D.

COST ANALYSIS

Acquisition cost estimates by models and by analysis of processes and techniques reflect potential cost savings for fiber optic interconnect systems as compared to wire harnesses. Since most models rely upon historical data and "conventional methods of business," it is implied that savings are realizable with technology maturity and with methods and techniques commonly employed.

Many options exist for production set-up and related costs. The most desirable option will depend on many factors such as levels of business forecasts, advancement of the technology, demands on existing harness/cable production equipment and facilities, facility space available for expansion or relocation, economic posture of the company, etc.

The potential for cost improvement in the manufacturing/fabrication process is promising. The development of automated equipment and expedient techniques is needed to exploit this potential; however,

a. cost elements related to operations and support aspects appear to have offsetting effects.

b. cost savings are realized through weight and size advantages, while losses occur through added inventories, training, and special equipment requirements.

c. reliability considerations have a similar neutralizing effect.

A detailed preliminary cost analysis is given in appendix E.

APPENDIX A
PRELIMINARY HARNESS DESIGN

SCOPE

This report describes the preliminary design of the fiber optic harness configurations, the Stand Alone Link, and the more complex interconnect harness. The stand alone link is a straight point-to-point design for use on add-on systems, retrofit applications, or as a substitute for a broken bundle within a complex harness. The interconnect harness design is the selected fiber optic configuration which will be a one-for-one replacement (physically) of a conventional wiring harness. This report details the preliminary design criteria, construction, and routing paths for these harness types.

STAND ALONE LINK PRELIMINARY DESIGN

The design criteria used for the Stand Alone Link were the requirements specified in the RFQ plus additional information gained from discussions with NOSC. The basic concept was to design the "Link" as if it were to be used in the retrofit of an existing aircraft and as such would be an add-on to existing cables and harnesses already in the airplane. The cable to be used for this Link was that specified in figure A-1. This cable, currently sourced by several manufacturers, consists of a 46-mil bundle of about 200 relatively high loss (approximately 400 dB/km) fibers. This bundle is sheathed in an inner Tefzel jacket which is in turn contained in a braid of Kevlar used as the strength member. The outer jacket consists of another tube of Tefzel. The total O.D. of the cable is 150 mils. This cable is quite sturdy and is capable of withstanding the internal environment of the E-3A airplane (except engine areas) without additional coverings. To provide as much information as possible relating to routing problems caused by different airplane environments, it was decided to route the link from an area inside the pressure hull to an outside area near the landing gear. This link then would have to be broken into two sections to allow ease of installation. It would have to pass through a pressure seal to get to the gear area and in the gear area it can be exposed to flying rocks, high velocity air flow with buffeting, effects of hydraulic fluid and other adverse environments. These additional stresses would demand that the link design, fabrication and routing provide a most complete set of safeguards for the system.

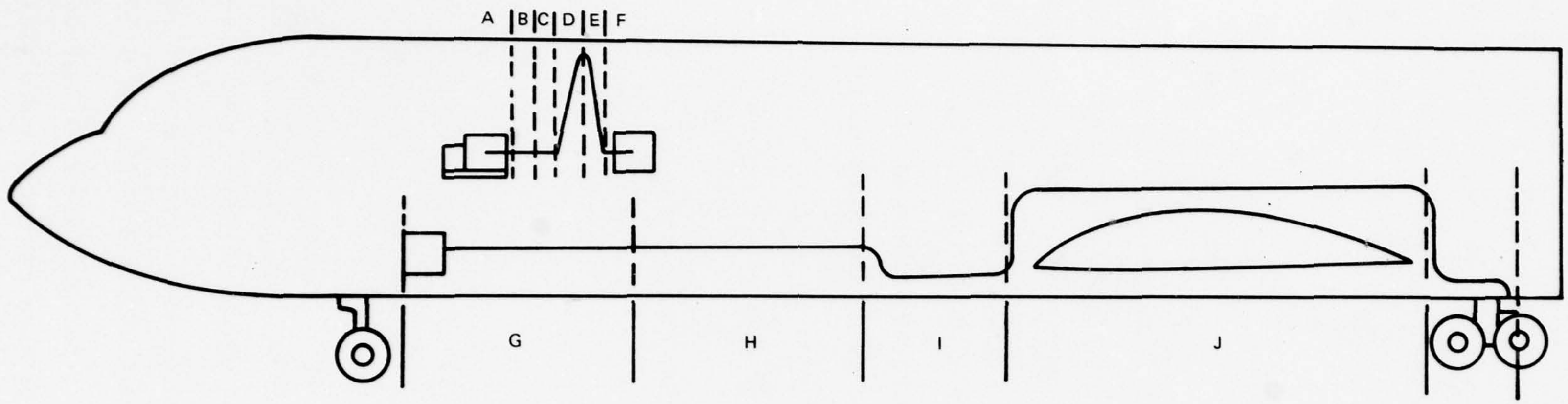
Link Routing

The actual path of the link through the aircraft is shown in figure A-1 and is detailed in the production illustration drawings delivered as a part of the Phase I. The link has to be designed in two sections, designated as "cable bundle, gear function transmitter, gear to disconnect assembly of" and "cable bundle, gear function transmitter, left hand E1-2 to wing body disconnect, assembly of" with drawing numbers 180-59002 and 180-59003 respectively. The first section of 180-59002 is generally designated on the drawings as FO-0002 and the second section FO-0003.

The first section starts at a box mounted on the lower part of the left gear main strut and in this extreme environment is routed through metallalic conduit until it is in the wing fillet area. Here the cable protection changes to a woven braid which is continued through the fillet up into the wheel well and the pressure seal. At the pressure seal the cable is enclosed by a seal fitting and packing. Once inside the seal area no further protective covers are required. This section of the link is then terminated in a bulkhead receptacle. The second and final section of the link plugs to the previous bulkhead receptacle end, continues unjacketed over the wing spar, down into the lower bay of the plane, being routed in the ceiling of the bay, all the way forward until it is routed down the sidewall to the E1 rack where its plug mates with the E1 rack receptacle.

Link Construction

The details of the link construction are illustrated in the manufacturing plans in which are located the "plug maps," wire lists, and connector designations. In the case of the link the four 4-pin connectors chosen (3 plugs and one receptacle) were those manufactured by Amphenol and designated 801-104-5005 and 801-105-5004 for the plugs and receptacle, respectively. The cable type for the 4 cables on the link is that discussed under design criteria.



A	–	180-59015-2	G	–	180-59046-2
B	–	180-59019-2	H	–	180-59038-2
C	–	180-59035-2	I	–	180-59033-2
D	–	180-59044-2	J	–	180-59041-2
E	–	180-59034-2	K	–	180-59031-2
F	–	180-59107-2			180-59088-2
					180-59061-2

FIGURE A-1. Stand-Alone Link Routing.

The conductor, outer braid, ties, and clamps used to fabricate and support the link in the installation are called out in fiber optics process specifications. These process specifications are basically standard wire process specifications that have been modified to be compatible with fiber optics technology.

FIBER OPTICS INTERCONNECT HARNESS

Design criteria

The choice for the interconnect harness is that originally discussed in the proposal and is designated as the E3A "Cable Bundle B169, B171 flight deck audio panels to E11 (ABS), Assembly of". This cable number of the E3-A conventional cable is W1870. The hybrid fiber optics counterpart is numbered FO-0001 and its drawing number is 180-59001.

This particular cable was selected because of its typical complexity in design and installation. The cable has point-to-point interconnections of each of the following types:

twisted pair, digital data	6
twisted pair, audio	12
single wire, condition/no condition info	4
grounds or shields	18
jumpered wires	12
power leads	3

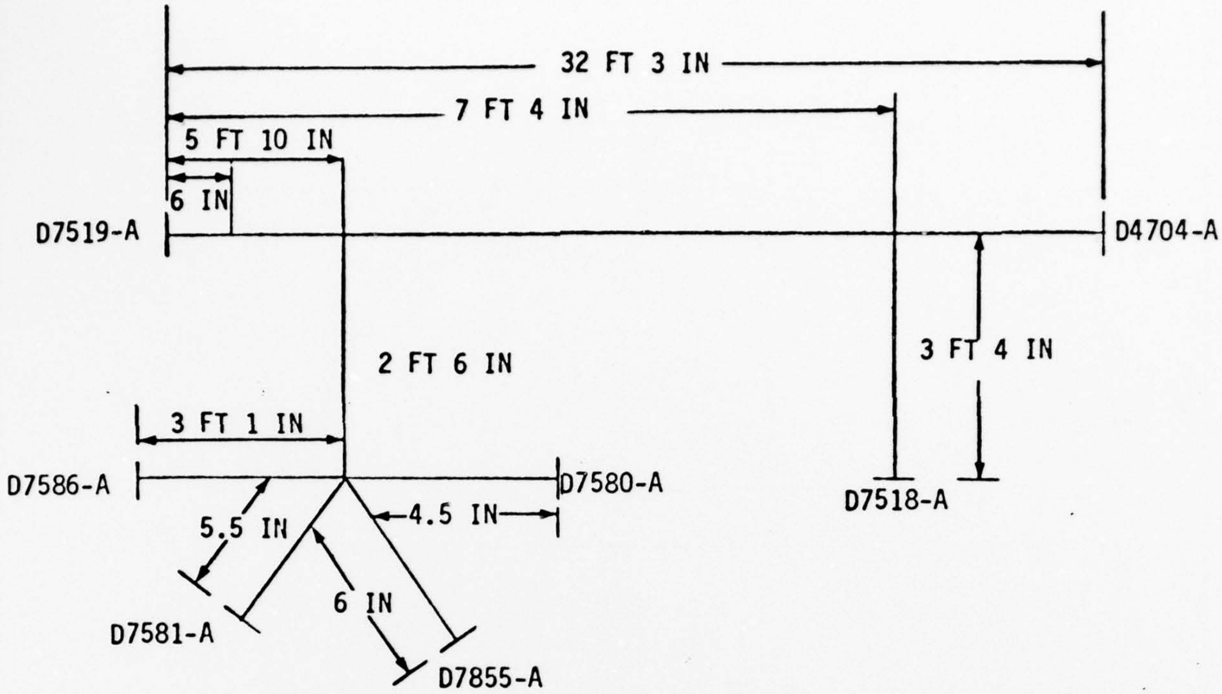
The present cable is physically configured as shown in figures A-2 and A-3 and is made up using the material detailed in Table A-1. Some of the pertinent design criteria are:

The audio circuits have TEMPEST secure requirements.

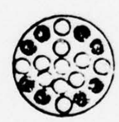
The interrogation data, 10VDC, and subscriber station data-5VDC circuits are digital and require shielding from the audio circuits.

The external jumpering of 4 pins is required to eliminate 400-Hz hum which is caused by magnetic coupling in the connector.

The series of jumpers to ground in D4704P is to provide a ground plane ground plane separation between the audio and digital circuits through the connector.



11 F/O CABLES



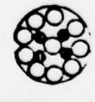
4 TWISTED PAIRS

TIE 8-12 IN.

TYPICAL OVERALL HARNESS

D7580-A, D7581-A
D7855-A, D7856-A

3 F/O CABLES



D7518-A
D7519-A

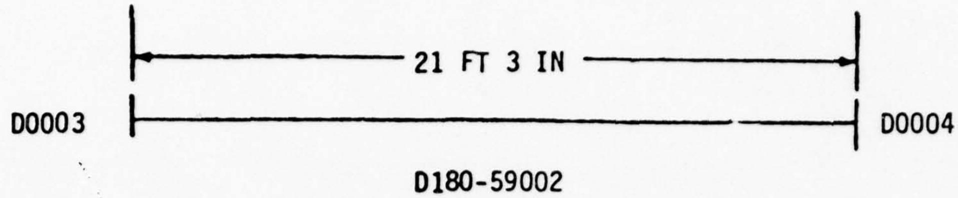
10 F/O CABLES + 2 TWISTED PAIR

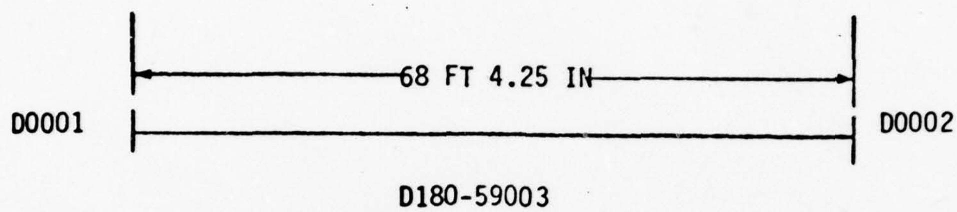
D4704-A
8 F/O CABLES +
4 TWISTED PAIR

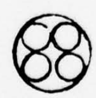
180-59001 HARNESS, WITH FIBER OPTICS F/O

FIGURE A-2.

SIZE	CODE IDENT NO.	
A	81205	D180-24693-4
SCALE	REV	SHEET 13







4 F/O CABLES

HARNESS CONFIGURATION

180-59002 and 180-59003 STAND-ALONE LINK

FIGURE A-3.

SIZE	CODE IDENT NO.	
A	81205	D180-24693-4
SCALE	REV	SHEET 14

PART NUMBER	DESCRIPTION	QTY
MS 27467T23B53P	PLUG - ELECTRICAL	1
MS 27467T15B35SA	PLUG - ELECTRICAL	2
MS 27467T11B35S	PLUG - ELECTRICAL	4
MS 27506B15-1	ADAPTER	1
MS 27506B23-1	ADAPTER	1
M81381/12-22-N	WIRE - SINGLE CONDUCTOR	58 Feet
M27500-22-MY2U00	WIRE - TWISTED PAIR	219 Feet
M27500-22-MY2T12	WIRE - SHIELDED TWISTED PAIR	204 Feet
TEFLON TAPE	.005 TO .020 THICK - WIDTH AS REQUIRED (SEPARATOR TAPE).	---
BRAIDING MATERIAL	SHIELD - WIRE, ANNEALED NICKEL PLATED COPPER WIRE PER ASTM B355-65T, SIZE AS REQUIRED	---
	OUTER JACKET - THREAD, HIGH TEMPERATURE POLYAMIDE (NOMEX) CONSTRUCTION #2455 NATURAL COLOR	---
	BELDING HEMINGWAY CO. INC 1430 BROADWAY, N.Y. 10018	

TABLE A-1. WIRE BUNDLE ASSEMBLY MATERIAL

The overall shield is to meet EMI-EMP and TEMPEST requirements.

This harness is produced in the Boeing Commercial Airplane Company's Harness Assembly shop. The tools used in the fabrication of this harness include:

- One Form Board
- Insulation Tools
- Stripping Tools (automatic or hand)
- Crimp Tools
- Marking Machine (Hot Stamp)
- Seal rods for unused pins

The fiber optic harness to replace the proposed wire harness is to be fabricated so as to physically conform in all respects except for the actual connector terminations. Terminations have to be chosen to allow completion of all data links within the original harness.

The twisted pairs used in this harness are used to supply dc power and ground and were left in this cable because it is expected that this type of Hybrid F.O./ wire cable assembly will be common in this future technology. One connector terminating 3 F.O. cables will use single fiber technology so that processes relating to this type of cable will be included in the development program. As this harness assembly is completely inside the pressure hull, different construction and installation procedures will be followed than with the stand-alone link.

Harness Routing

The FO-0001 harness will be routed as illustrated in Figure A-4 and as detailed in the P.I. drawings. The route chosen is identical to that of the conventional cable. This routing is an original installation routing procedure but should be compatible with rework or retrofit procedures.

Harness Construction

Cable

The fiber bundle chosen for the harness construction will be of a lighter duty type than that of the link and will consist of a 46-mil bundle of ≈400dB/km loss fibers covered with a protective Tefzel jacket. This cable is available from three suppliers. The lighter cable can be used in this application because

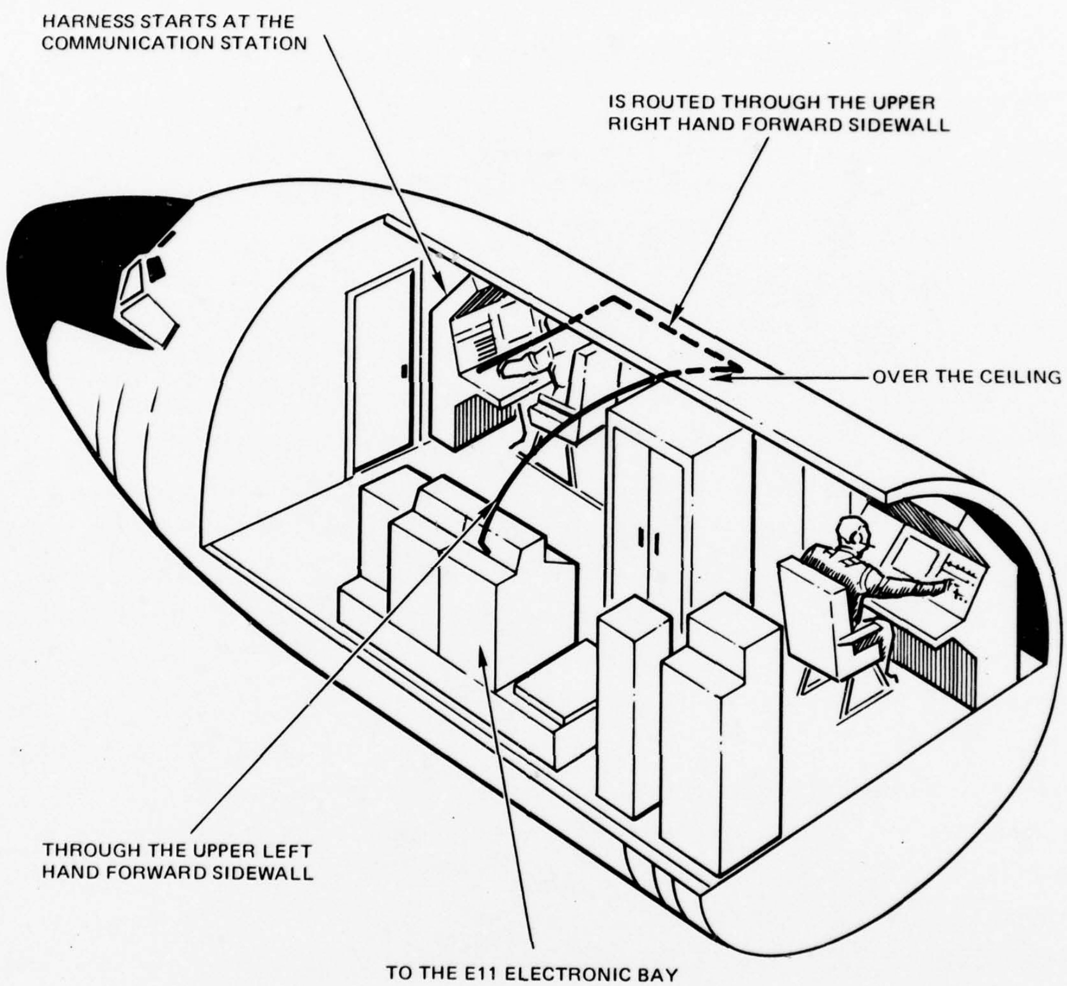


FIGURE A-4. Simplified Details of the FO-0001 Harness Routing.

The large number of cables in the bundle (4 to 19) will provide mutual stiffness and support.

The outer braided cover will provide strain relief and also protect the cables from abrasion and any handling damage.

The routing of the harness is completely in the interior of the E3-A aircraft and is protected by paneling and cobundling with other harnesses.

The lighter cable will save weight on the aircraft and cut down the bulk and stiffness of the harness compared to the heavy duty cable.

The cost is less.

The single fiber cable to be used will be large-core medium-loss glass-on-glass material with an outer Tefzel jacket. This will give necessary support and still provide the flexibility needed for the smaller harness ends. The large core material (8-10 mils) was selected over the almost standard 5 mil (3 mil core) material for this application for several reasons. The larger core material is easier and therefore less expensive to terminate because tolerance requirements are much less as compared to the 3 mil core diameter. Input coupling loss (source to fiber) should also be significantly less for larger area (than laser diode) emitters because of the 9 times larger input area and also because of the significantly larger numerical aperture than the 3 mil cover diameter materials (in the range of 0.40 vs 0.20). The attenuation characteristics are quite a bit higher than the small core materials 50 dB/km vs $<$ 10 dB/km, but in airplane applications with runs generally much less than 30 meters this amounts for a 30-meter length a difference 1.5 dB (1.8 dB - 0.3 dB), which is more than offset by the lower insertion losses. Cost of this material is very close to that of small core material and is generally less than the fiber bundle material.

Conventional wire used in this cable will be standard twisted pair 22 ga. Teflon coated stranded wire.

Connectors

Two types of connectors were chosen to be used in this cable for the three larger termination count connectors (D4704P; D7518 and D7519). A Hughes C21 series 20 termination connector, rectangular in shape with center jackscrew per MIL-C-85028. This is a front insert/removal unit and is capable of handling single fiber, fiber bundle, and wire terminations.

The four 4-pin connectors chosen for the harness (D7580, D7581, 7855 and D7856) are the ITT Cannon PVA/MIL C-83723 series and are round plugs utilizing rear release and insertion. They are also capable of terminating all three types of cable to be used on the program.

CONCLUSIONS

The two harness designs should provide a basis for development of all needed specifications, utilize the major types of fiber optics transmission media and provide actual usage information on three different types of state-of-the-art multipin connectors. While a lesser number of types of connectors could have been used at probably less overall cost and with less chance of potential problems or failures, it was felt that the broader base of knowledge gained from the multiple sources would provide greater information at minimal extra cost.

Choice of cable materials (1 single-fiber and 2 fiber-bundle types) reflects current industry state of the art and should provide us with a baseline for cable materials over the next several years.

The routing paths of the two harnesses provide a wide variety of aircraft environments from benign to severe and so should provide excellent vehicles for development of the needed routing and assembly technology and specifications.

APPENDIX B
PRELIMINARY INSTALLATION PLAN

This report describes the materials and processes required and techniques to be used in the fabrication and installation of the FO-0001 fiber optics harness and the FO-0002 - FO-0003 "Stand-Alone Link". The details peculiar to the individual cables are described in the D180-24693-2 document while individual process and manufacturing techniques for all fiber optics cables are detailed in the general procedures document, appendix C. This set of general procedures covers both single-fiber and fiber-bundle cables and harness and covers identification, marking, installation, and fabrication.

1.0 SCOPE

1.1 This specification covers the assembly and installation of fiber optics cables and harnesses in military aircraft.

1.2 In case of conflict between this specification and Engineering Assembly and Installation Drawings, the information of the engineering drawings shall have precedence.

3.0 CONTENTS

4.0 ASSEMBLY OF FIBER OPTICS CABLES AND HARNESSES

4.1 CABLE IDENTIFICATION (Marking)

4.1.1 Physically identify cable as follows:

1. Include in each identification all the information specified by the Bundle Assembly Drawing.

2. Where the Bundle Assembly Drawing specifies identification of the bundle number and cable number, use only the hot embossing on sleeve or tape methods of Appendix B-1.

4.1.2 Cable Identification Sleeves and Tape

4.1.2.1 a. Identification of cables by means of sleeves or tape is required within 6 inches of the terminating points and within twelve inches of each side of a pressure bulkhead.

b. Identification of unmarkable cables by means of sleeves or tape is required only at terminating points and may be staggered up to twelve inches from termination points to reduce bulk and within twelve inches of each side of a pressure bulkhead.

c. For cable bundles using protective "Expando" sleeving over the cable or harness, the cable identification sleeves or tape may be staggered up to a maximum of twelve inches from termination points to reduce bulk.

4.1.2.2 Include color coding as indicated by the Bundle Assembly Drawing on identification sleeve or tape when these are installed around a multi-conductor cable. No color coding is required when the identification sleeve or tape is used on individual cables of a bundle.

4.1.2.3 Add identification sleeves to unidentified cables on vendor furnished components when numbers are required by the Bundle Assembly Drawing.

1. Imprint the cable numbers assigned by the Bundle Assembly Drawing on the identification sleeves.

2. Locate an appropriate sleeve on each cable within three inches of the component.

4.1.2.4 Where heat shrinkable sleeving is used for cable identification, the actual shrinking operation is required only where necessary to prevent the sleeve from sliding out of position on the cable during normal service.

4.1.2.5 When marking RT 876 heat shrinkable sleeving, use a type temperature of $500 \pm 25^{o}F$. Regulate the machine pressure and dwell time to provide the maximum pigment transfer from foil to sleeve.

4.1.2.6 Quality Control shall determine, on a surveillance basis, that the impressions are clear and legible.

4.2 BUNDLE IDENTIFICATION

4.2.1 Bundle Assembly Part Number

4.2.1.1 Bundles shall be part numbered per 4.2.3.

4.2.1.2 Bundle assembly part numbers shall consist of Bundle Assembly Drawing numbers and dash numbers. Example: 180-50101-1

4.2.1.3 Cable bundle assembly part numbers shall be located as specified on the Bundle Assembly Drawing. Markers shall be located at one end of the bundles if locations are not given by the Bundle Assembly Drawing.

4.2.2 Cable bundle F/O number.

4.2.2.1 Cable bundle F/O numbers shall be placed on cable bundles per Appendix B-1.

4.2.2.2 Bundle F/O numbers shall consist of the letter F/O followed by the last four digits of the Bundle Assembly Drawing number with the leading zeros omitted.

EXAMPLE: 180-50001 = F/01
180-51121 = F/01121

4.2.2.3 Bundle F/O number markers may be placed from six to twelve inches from the bundle terminations and at six foot intervals throughout the length of the cable bundles that contain only cables that cannot be marked by direct imprinting.

4.2.2.4 Bundle F/O number markers shall not be used on cable bundles that contain any cable that can be marked by direct imprinting.

4.2.2.5 For cable bundles with protective "Expando" sleeving, the F/O number (yellow wire bundle ID) shall be installed in the overlap area per Figure B-1.

NOTE: Mate with and F/O No. may all be on the same identification marker.

4.2.3 Materials for Cable Bundle Identification Markers.

4.2.3.1 'T&B' 650-51983 nylon perforated tape (or equivalent) imprinted with the information along the length of the tape and centered with respect to the tape perforations shall be optional material. See Fig. B-2 and B-3.

CAUTION - SLEEVE MATERIAL USAGE IS DETERMINED BY TEMPERATURE TYPE I OR TEMPERATURE TYPE II, AND HYDRAULIC FLUID OR NON-HYDRAULIC FLUID AREAS.

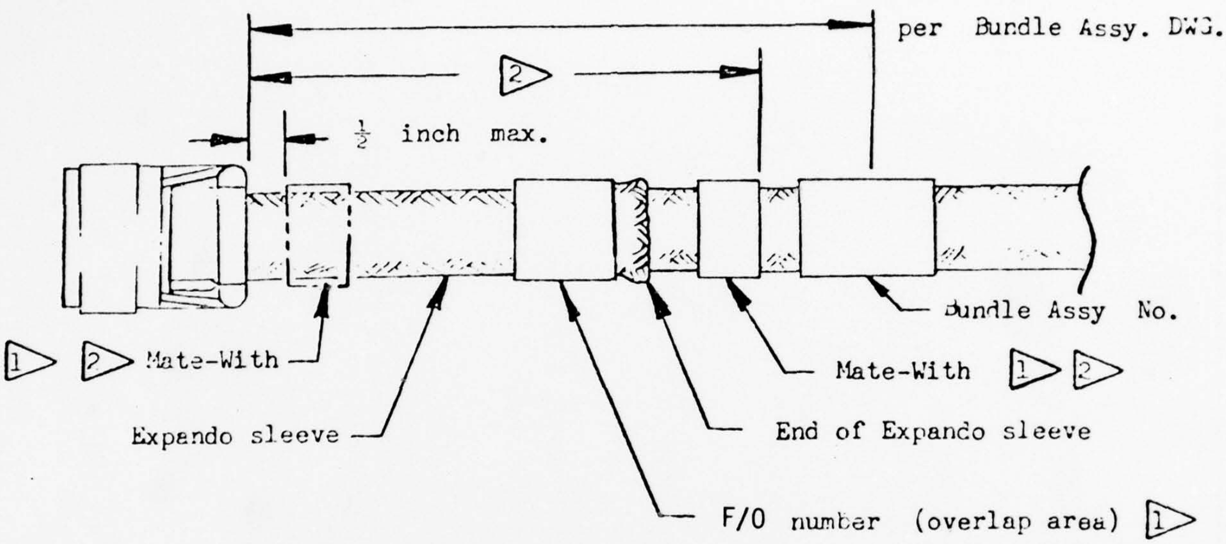


FIGURE B-1

1 Mate-With and F/O number may all be on the same identification marker.

2 If Mate-With identification would not be visible after installation, it may be installed loosely around Expando sleeving within ½ inch back of connector hardware.

SIZE	CODE IDENT. NO.	
A	81205	D180-24693-2
SCALE	REV	SHEET 6

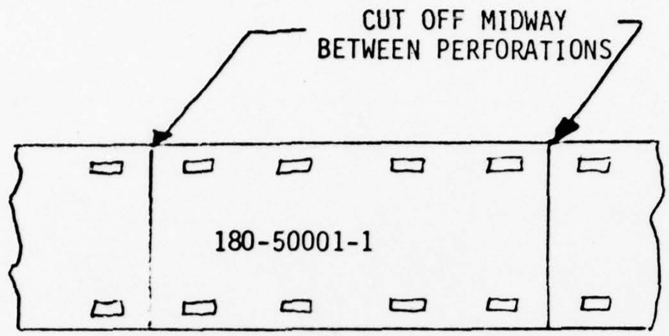


FIGURE B-2

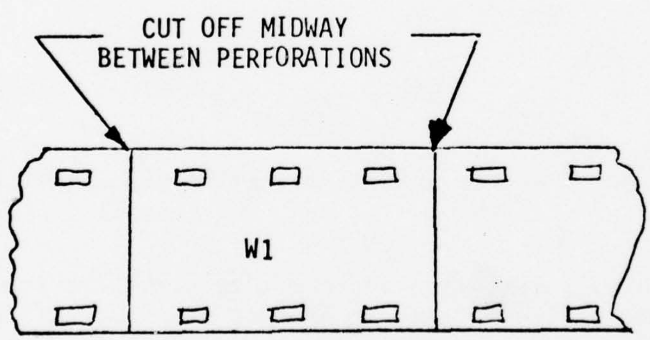


FIGURE B-3

SIZE	CODE IDENT. NO.	
A	81205	D180-24693-2
SCALE	REV	SHEET 7

4.3 REFERENCE POINT INDICATORS (PI Markers)

4.3.1 Production illustration (PI) reference points shall be identified per Appendix B-1.

4.4 SPECIAL INFORMATION MARKERS

4.4.1 Install special information markers on individual cables or on entire bundles as specified by the Bundle Assembly Drawing.

4.4.2 Locate the markers as near the end of the cable or bundle as possible - unless otherwise noted in the Bundle Assembly Drawing.

4.4.3 Use the materials and installation methods as specified for connector information by Appendix B-1.

4.4.4 Imprint on the marking media that information which is specified by the Bundle Assembly Drawing.

4.5 CONNECTOR IDENTIFICATION

4.5.1 a) A "Mate With" tape is required for all plugs and receptacles that are not identified with a "P" or "J" suffix. The "Mate With" information on the tape shall match the equipment item numbers shown in the parts list of sheet 1 of the Bundle Assembly Drawing.

b) Mate-With tape is not required on seal fittings.

4.5.2 Identification of equipment mating connectors will be per Appendix B-1.

4.5.3 In-line connectors will be identified per Appendix B-1, normally the "Mate-With Dxxxx" notation will be omitted.

4.5.4 Use of nylon tags, per Para. 4.2.3, for connector identification in Type I and Type II temperature areas and in either hydraulic fluid or non-hydraulic fluid area is permitted.

4.5.5 For bundles with protective Expando sleeving, the Mate-With tape or sleeving shall be installed per Figure B-1. When the PI markers are located in the Expando area 18 inches back of the connector or on a short cable bundle with Expando on the entire bundle, the PI marker shall be installed tight and secured with a bundle tie, making the flag marker stationary at the location specified by the Bundle Assembly Drawing.

4.5.6 Connector identification markers are not required when connectors are attached permanently to support plate with connector identification marked thereon. "Mate-With" information is not required.

4.6 SPLICE IDENTIFICATION

4.6.1 Where physical identification of a cable splice is specified by bundle assembly or bundle installation drawings, identify the splice as follows:

4.6.1.1 Use RT-876 sleeving with sleeve size such that it fits loosely around the cable of cables to be spliced, yet will not slide over the splice.

4.6.1.2 Mark the splice number (SPXXX) on the sleeve per Appendix B-1. Do not include leading zeros of the splice number. For example, splice number SP002 as shown on the cable bundle assembly drawing shall appear as SP2 on the identification sleeve.

4.6.1.3 Slide the sleeve over the cable prior to the installation of the splice.

4.6.1.4 Do not shrink the heat shrinkable sleeve.

4.6.1.5 The sleeve must be located within three inches of the splice.

4.6.2 When application of a sleeve is impractical, such as on a completed bundle assembly, pressure sensitive tape may be used. Imprint the splice number and apply the tape within three inches of the splice per Appendix B-1.

4.7 IDENTIFICATION MARKERS (GENERAL)

4.7.1 Use split or whole sleeves tied or shrunk as applicable. The use of pressure sensitive tape is acceptable.

5.0 INSTALLATION OF FIBER OPTICS CABLES AND HARNESSES

NOTE: Mixed electric and fiber optic cables must be installed using applicable practices for electrical cables plus these extra installation notes applicable to fiber optics.

5.1 ROUTING OF CABLE BUNDLES

5.1.1 Install all cables per Appendix B-3 except as noted.

5.1.2 Install cables with sufficient clearance to prevent chafing of the installed bundles against sharp edges of structures, equipment, etc. (1/8 in. clearance minimum unless secondary protection is provided by engineering drawing). Normal bundle slack may require 3/4 in. separation to account for vibration and bundle movement.

5.1.2.1 When not specifically controlled by engineering drawings, slack portion of bundles may contact smooth flat surfaces and smooth radii 1/8 in. or larger of either metal or plastic. This does not apply to the engine area.

5.1.2.2 Fiber optic cables may be scuffed on the surface without degradation of performance. Scratches deep enough to damage reinforcing braid is rejectable.

5.1.3 Bundles shall not be tied together unless required to provide support for small bundles. When structure for clamping is not available, bundles per above shall be tied to adjacent cable bundles to achieve support.

5.1.4 Reference Point Indicators (PI Markers) for Production Facility.

5.1.4.1 When reference point indicators are specifically called out on the installation drawing, (not all bundle assemblies through a reference location are considered critical at that point) locate the reference point indicators on the side of the support device indicated by the cable bundle installation drawing. The gap between the support device and the near edge of a green indicator will be 1/2 in. $\pm$ 1/2 inch. Do not use green indicators in fuel tanks.

5.1.4.2 Allow Reference Point Indicators under the Protective Sleeving.

5.2 CABLE SUPPORTS

5.2.1 Cable bundles shall be supported by channel raceway clamps or loop clamps as specified on the wire provisions installation drawings. Bolt and nut installation shall be per standard practice.

5.2.2 Loop Clamps shall be installed as follows:

1. Cushion-loop clamps (such as ADEL part number 5095__) shall be used for general purpose clamps in nonpressurized areas and for the following special applications in pressurized areas:

   A. Bundles in high temperature areas (275°F or greater)
   B. Bundles 1.25 in. in diameter or larger

5.2.2 (Continued)

2. Nylon-loop clamps and plug fillers, when required, shall be used for general purpose clamps in pressurized areas for cable bundles less than 1.25 in. in diameter and with temperatures less than 275°F.

3. Nylon-loop clamps without fillers shall be used inside fuel cells.

   A. Where proper grip of the cable cannot be achieved with standard size clamps, the clamps may be sleeved per the following method:

   B. Select a length of shrinkable tubing such as MIL-I-23053/ (color optional). Slide the tubing onto the clamp so that the tubing will not interfere with the closing of the empty clamp.

   C. The tubing shall not be installed in more than every third clamp on straight runs and shall be installed in each clamp in curved runs. Do not shrink tubing.

5.2.3 Raceway Clamps

5.2.3.1 Install clamps on channel as follows:

1. With cable bundles distributed in the channel, place the clamp in position with the cushion against the cable bundles and the clamp centered over the channel.

2. With the heel of the hand, press the clamp until the hook on each end has seated in the appropriate slots in the channel.

3. To properly grip the bundles, the sponge cushion must be depressed to a thickness of not less than 1/4 in. The cushion should be depressed to a thickness of not less than 3/8 in. (see Figure B-4). Check to determine that the bundle distribution within the channel is such that none of the bundles are free to move.

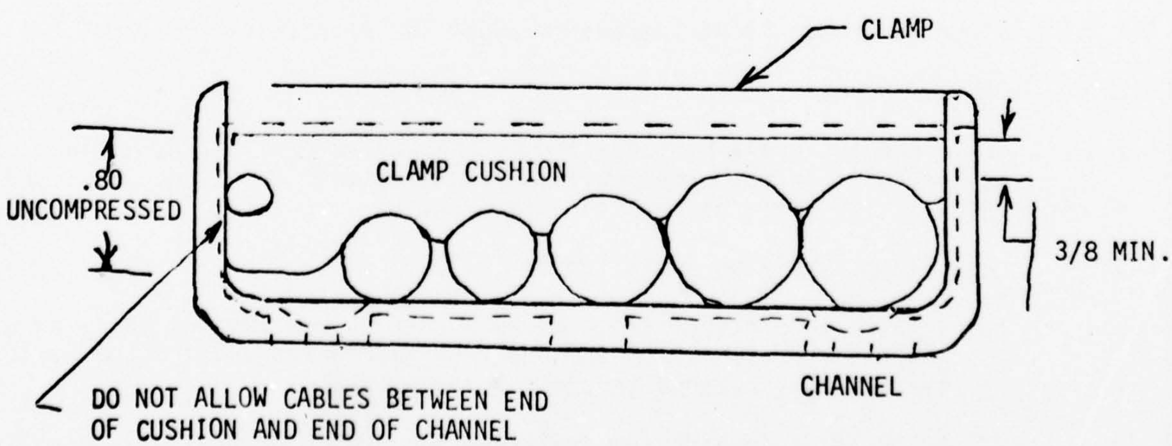


FIGURE B-4

SIZE	CODE IDENT. NO.	
A	81205	D180-24693-2
SCALE	REV	SHEET 11

5.2.3.2 Where a short channel is not available, allow trimming of a longer part to the dimensions of the required shorter part. Break sharp edges of reworked area.

5.2.4 Nylon Clamps

5.2.4.1 Where nylon clamps are specified use only Olympic Plastics Co. or Peco Manufacturing Co. clamps as required throughout the airplane.

5.2.4.2 When a nylon clamp is used with a NAS 42 spacer or a metal stand-off, install washers as shown in Figure D-5.

CAUTION: Do not use washers within a fuel tank.

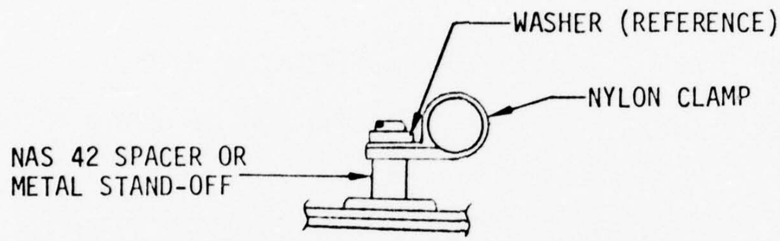


FIGURE B-5

5.2.5 Flip Type Grommet (NAS 1368N)

5.2.5.1 Install flip grommets with Western Sky Industries tools WSI-T-3 or WSI-T-32 or WSI-HT-3 through WSI-HT-32 or equivalent.

5.2.5.2 To replace a damaged flip grommet, carefully cut the damaged part out of the hole in structure and install a new grommet with the tool specified in Paragraph 5.2.5.1.

5.2.5.3 If cables are installed through the damaged grommet, cut the grommet as required to remove it from the cables. Install the replacement grommet as follows:

1. Flip the grommet with tool specified in Paragraph 5.2.5.1.

2. Split the grommet as shown in Figure B-6 using a sharp knife or razor blade.

3. Apply adhesive to the grommet.

4. Install the grommet around the cable and in the hole of the structure.

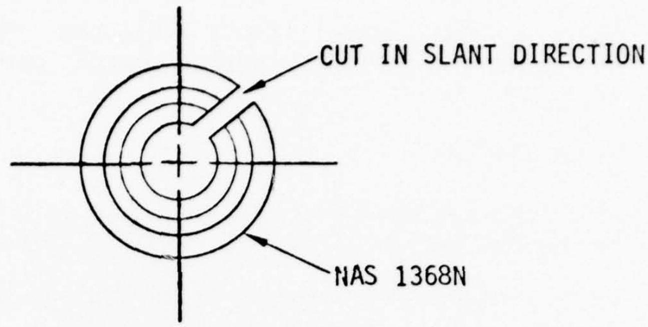


FIGURE B-6

5.2.6 Use NAS 603-( ) screws for installation of all single lobe wire bundle support clamps.

5.2.7 Dakota Cab-L-Tite Clamps shall be installed as follows:

1. Select a Cab-L-Tite clamp size which will provide a minimum of one notch above both ends of the keeper when installed.

2. Select countersink screw or hex head bolt as applicable. Insure that the head of the fastener does not protrude above the base of the clamp into the cable gripping area.

3. Mount Cab-L-Tite clamp as specified by installation drawing, lay cable bundle in clamp and install keeper, insuring bundle is securely held.

5.3 REPAIR OF FIBER OPTIC BUNDLE

1. If the outer jacket has minor scuffing such that the inner strength member braid is not exposed, apply a coating of Vyna-Kote No. 6 (Spectra-Strip Wire and Cable Corporation, Garden Grove, California).

2. If the outer jacket is scuffed such that the strength member braid is exposed but is not damaged, apply one coat of Vyna-Kote No. 6 and allow to dry for 3-5 minutes. Wrap area with .003 - .007 fiberglass tape, tie ends with nylon or dacron cord and cover with another coat of Vyna-Kote No. 6.

5.4 RACEWAYS AND CONDUIT

5.4.1 Position cable bundles within raceways as specified in cross-section views on the Wire Bundle Installation Drawings.

5.4.2 Mark and install pull-cord as follows when specified on engineering drawings.

1. Imprint the words "Pull-Cord" on one side of the pull-cord at not more than 15 in. intervals throughout its length using hot embossing machine with D11-51 black foil. Use Bently-Harris Mfg. Co. TG. 40 cord. Optional: Dodge Fibers Corporation TB303.

5.4.2 (Continued)

2. Install the pull-cord in the conduit or raceway with the excess length divided approximately equal and coiled at each end of the inaccessible area. Tie the two coils to the bundle with which it is routed. Do not include the pull-cord under any bundle ties or clamps.

3. Replace the pull-cord per 1 and 2 above if for any reason it is used prior to delivery of the airplane.

5.4.3 Cetyl Alcohol may be used as a lubricant for installations in conduit.

5.5 BEND RADIUS

5.5.1 Use the bend radii specified in Appendix B-3. Where the stiffness of a cable bundle will not allow bending to the minimum, it is permissible to remove the bundle ties locally. After the bend is formed, retie the bunder per Appendix B. The bundle need not resume a round, cross-section in the bend area.

5.6 FUEL TANK BUNDLES

5.6.1 Do not use cable bundle ties within any fuel tank area.

5.6.2 Do not use tapes or tied-on markers on cable bundles within any fuel tank area.

5.6.3 Wire bundle clamps within fuel tanks shall be procured from the Olympic Plastics Col or the Peco Manufacturing Co.

5.7 CONNECTOR INSTALLATION

5.7.1 Install connectors with the major keyway in the "UP" or "FORWARD" position, unless otherwise noted on drawing.

5.7.2 Torque all firewall connector coupling rings per supplier's specification prior to lockwiring.

5.7.3 Where the drawing specifies application of a "red dot", the coupling nut of threaded coupling connectors shall be safety wired.

NOTE: Safety wiring or otherwise mechanically locking is required to prevent loosening under vibration when installed in engine nacelles, in other areas of severe vibration (excluding those on shock-mounted equipment), and in areas which are normally inaccessible for periodic maintenance inspection of the aircraft.

5.7.3.1 The "red dot" shall be 1/2 inch diameter painted or affixed on the structure adjacent to each connector. The material of the painted "red dot" shall be protective enamel. Color shall be "red" #11136 per federal standard 595, or equivalent.

5.7.3.2 Clean the surface to be painted using an appropriate solvent. Prepare the paint material by mixing the enamel base and catalyst in the proportions specified by the vendor in a clean container. Do not use thinner or reducing agent.

5.7.3.3 Use a modified felt tip applicator. Modify the standard conical felt tip to a flat tip, 1/2 inch in diameter. To use, saturate the tip and press lightly against the prepared aircraft surface. Paint should be dry to touch in 5-15 minutes and will achieve full chemical resistance in approximately 7 days at ambient temperature.

6.0 INSPECTION OF INSTALLED FIBER OPTIC BUNDLES

When the installation of the cable is complete per the Wire Bundle Assembly, the installation procedure and this document, the quality control department shall inspect the finished installation to assure the bundle has been installed in a workmanlike manner. The installation shall be specifically examined for the following:

6.1 SLACK

6.1.1 Sufficient length of individual conductor lengths shall be available for 3 reterminations. This results in additional bundle slack.

6.1.2 The bundle slack shall be evenly distributed between P.I. location markers. The additional slack for retermination should be included in the slack of the first 6 feet at each end of the bundle.

6.1.3 The bundle shall be free about hinge joints with sufficient slack to prevent binding when the hinge is fully opened.

6.1.4 Where equipment may be removed with the bundle installed, sufficient slack should be available to provide operating clearance during rework.

6.1.5 Slack for normal coupling and uncoupling of connectors should be provided.

6.1.6 On shock mounted equipment, the bundle slack should provide for full traverse of the equipment without transmitted strain to the bundle.

6.1.7 Normal expansion and contraction of the airplane should not exert strain on the bundle. This is especially critical in long straight runs where the effect is least obvious to the inspector.

6.1.8 Make sure that there is sufficient separation from adjacent surfaces so that bundles with normal slack will not make contact.

6.2 Drip Loops

a. To prevent fluids or contaminants from entering junction boxes, connectors or other enclosed items, use drip loops unless potting is used in such a way as to accomplish the moisture barrier.

6.2 (Continued)

b. Locate drip loops so that fluid will not drip on electrical equipment.

6.3 Bend Radius

The bend radius shall be no less than 6 times the finished cable diameter or 1.5 inches (3 inch bend diameter), whichever is greater.

6.4 Bundle and Cable Support

Cable clamps must be compatible with the area where the cable is installed, and the smallest which will hold the bundle without crushing or pinching the cable, but will not permit abrasive movement.

6.5 Coupling of Connectors

a. Make certain that the plugs and receptacles are properly mated and fully coupled. Check for tightness by hand and only in the direction of coupling. On bayonet types the locking pin should be visible.

b. Check that safety wiring is installed properly.

c. Make certain that the connector number and mate-with information are per drawing.

6.6 Bundle Identification

Check that cable and bundle marker tapes or sleeves, and marks on cable are per drawing and do not penetrate the cable jacket.

6.7 Continuity

Prior to closure of the connectors, check continuity of the cables and the integrity of each circuit from the other. Fiber optic cables are tested with a light source or per the cable drawing. Electrical cables are tested by voltage measurement.

APPENDIX B-1

IDENTIFICATION OF FIBER OPTICS CABLE, CABLE BUNDLES, AND HARNESSES

1.0 SCOPE

This specification contains engineering requirements for the identification of production cabling.

2.0 CONTENTS

3.0 REQUIREMENTS AND VERIFICATION

3.1 REQUIREMENTS

3.1.1 General

a. Identification is not required on cable less than 3 inches long or within concealed runs.

b. Identification is not required on module bundles or connectors when:

(1) No form board is required.

(2) The bundle is formed on the module.

(3) The module is not a panel module.

c. The cable identification information code printed on the cable, tape, or sleeve must resist environmental characteristics to the class and grade levels noted on the engineering drawing or data processing (EDP) paper.

3.1.2 Identification of Cable Covering Suitable for Direct Printing

a. Print identification directly on outer surface. The printed identification shall not puncture or damage the cable. After printing, bending and/or flexing of the cable shall not cause cracks or splits in the cover.

b. A complete identification code shall be legible within 12 inches of the cable termination points, excluding splices, and at 15 inch maximum intervals throughout cable length.

3.1.3 Identification of Cable Covering Not Suitable for Direct Printing

a. Apply a yellow heat shrinkable sleeve or identification tape, printed as indicated below.

b. Use cable number and color code specified by Engineering Drawing. Space the color code characters so they do not appear as an integral part of the wire number.

Example:	IN260H18	GR	L24D18	Y
	IN261H18	R	L24D18	BR

c. Identify spare cable stubs with the connector contact letter or number. When a contact is identified by a lower case letter, the corresponding cable will be identified by an upper case letter followed by a cash.

d. Where two or more unterminated cables, bearing the same identification, are routed together in a single group or bundle, include the code number of the plug in which they terminate on the corresponding cable.

e. If Engineering Drawing requires that the cable(s) or the bundle be protected with sleeving, cable identification may be printed directly on the sleeving.

f. Install printed sleeves or tapes:

(1) Within 3 inches of entrance/exit points of concealed cable runs.

(2) Within 3 inches of connector cable clamps and terminating points, excluding splices, and at 6 foot intervals throughout cable length.

(3) Within 12 inches of each side of bulkhead seal fittings.

(4) So they are outside the connector grommet, potting area, or adapter clamps.

(5) By tieing or shrinking all sleeves unless their movement is restricted to not more than 3 inches by a bundle tie, clamp, shield, etc. Do not shrink the sleeve over a bundle tie. If the sleeve is split and tied in place, it must overlap itself 1/4 inch minimum.

3.1.4 Bundle Identification

Install a bundle number within 12 inches of each end of the bundle. Use an approved blue tape printed with 1/8 to 1/4 inch high characters. The prefix "ASSY" need not appear in the bundle number but each dash must be included.

3.1.5 Production Illustration Reference Markers

The "PI" markers may be applied to the cable bundle as an installation expedient. Use an approved (Appendix F) colored identification tape marked in accordance with the Engineering Drawing and production installation needs.

3.1.6 Connector Mate-With Markers

Print the connector mate-with information on an approved yellow identification tape and apply the tape to the cable bundle within 6 inches of the connector. The applied tape must not be attached to, or interfere with connector maintenance. Information may be abbreviated in accordance with MIL-STD-12. The equipment reference number, mate-with tape, and the equipment must agree. If no number appears on the equipment, do not print mate-with numbers on the tape. Use sequence depicted in Figure B-1-1.

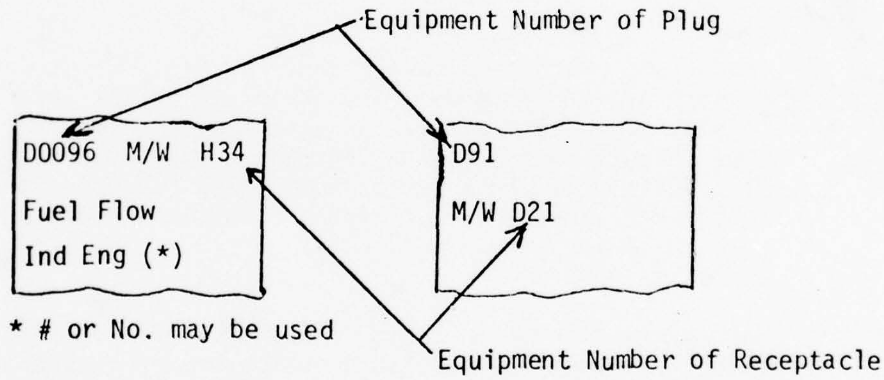


FIGURE B-1-1. EXAMPLES OF MATE-WITH MARKERS

3.2 VERIFICATION

a. In-process surveillance shall be maintained during production. Random test specimens of specific cable, tape, or sleeve type shall be supplied by Manufacturing when, and as, requested by Quality Control. The test specimens shall have been made using production equipment and material on wire, tape, or sleeve compatible with current design requirements.

b. Specimen shall be tested as indicated in Table B-1-1.

TABLE B-1-1

Marking Method	Application Class Per Appendix F	Test Required on Specimen		
		Fluid 3.2.1	Abrasion 3.2.2	Longevity 3.2.3
Hot Stamp	1	X	0	
	2		X	
Ink Ribbon	1	X	0	X
	2		X	X

0 = Specimens must be tested consecutively with previous test.
X = Specimens may be tested concurrently.

3.2.1 Fluid Test

Characters printed on cable, tape, or sleeve shall withstand a 24-hour minimum soak in an approved hydraulic fluid at 70 $\pm$ 2°C, followed by a 24-hour air dry at room temperature and remain legible after being subjected to conditions of 3.2.2.

3.2.2 Abrasion Test

Characters printed on cable, tape, or sleeve must remain legible to the unaided eye at a minimum distance of 15 inches in minimum daylight of 30 foot candles after 20 rubs with an abrasive felt (Federal Specification C-F-206b, Type III, Class 7A1) using 2 pounds of weight pressure (including the weight of the fixture) and a speed of 30 to 60 rubs per minute. The felt surface shall be 3/16 to 1/4 inch wide and completely contact the printed characters.

3.2.3 Longevity Test

Characters printed on cable, tape, or sleeve shall remain legible after a 24-hour minimum exposure in a weatherometer chamber to alternating cycles of ultra-violet light and typical tap water spray. The cycle periods shall be 102 $\pm$ .25 minutes of ultra-violet light and 18 $\pm$ .25 minutes of ultra-violet light plus typical tap water spray.

APPENDIX B-2

FABRICATION OF FIBER OPTICS CABLE BUNDLES/HARNESSES

1.0 SCOPE

This specification describes methods and fabrication materials for assembly of fiber optics bundles/harnesses.

2.0 CONTENTS

3.0 MATERIALS CONTROL

Material "type" classifies materials according to maximum continuous operating temperature listed below. Where drawing specifies a temperature "type" area only materials of that classification shall be used, except, where a specific material is not available, a higher temperature material may be substituted. When the specification or Engineering drawing calls out a specific material, no substitution shall be made. Where temperature "type" or material is not specifically designated, Type I materials shall be generally used.

Type I - to 200^{o}F
Type II - to 275^{o}F
Type III - to 350^{o}F
Type IV - to 500^{o}F

1 This material is resistant to Skydrol 500.

2 Except for the adhesive, this material is resistant to Skydrol 500.

3.1 TYPE I MATERIALS

3.1.1 Sleeving, Insulating

a. Sleeving; insulating, flexible, transparent, extruded vinyl, per MIL-I-7444, Type I, standard sizes as required in the following ranges:

Range I (20 AWG to 1/2 I.D. Incl.)
Range II (5/8 inch to 1-1/2 I.D. Incl.)
Range III (1-3/4 inches to 2-1/2 I.D. Incl.)

3.1.1 a. (Continued)

(1) The Borden Co., Chemical Division,
Resinite Department, Santa Barbara, Calif.
"EP-93C" For All Ranges

(2) The Wm. Brand and Co., Inc.;
Williamantic, Conn.
"Turbo 625" For Range I and II

(3) 3M Co.,
Irvington Division,
Freehold, New Jersey
"Irvington 3022" For All Ranges

3.1.2 Strip, Insulating

Strip; plastic, vinyl, transparent, flexible (material same as for sleeving per MIL-I-7444, Type I), .020 or .040 inch ± .0015 thick and .060 inch ± .0025 thick width as required (tolerance ± 5%) in 1/4 inch increments.

The Borden Company, Chemical Division,
Resinite Department, Santa Barbara, California
"CT-93C" for .020 inch
"EP-93C" for .040 and .060 inch

3.1.3 Tape, Insulating

a. Tape; electrical, vinyl, pressure sensitive, black unless otherwise noted, opaque, per MIL-I-7798, .007 ± .001 inch thick, width as required (tolerance ± 1/16) in 1/4 inch increments.

(1) Permacel, New Brunswick, New Jersey
"P-29, Black"

(2) 3M Co., St. Paul, Minn.
"Scotch #33"

(3) Technical Tape Corp., New Rochelle, New York
"Tuck No. 330, Black"

3.1.4 Tape, Cushioning (Cable Clamp)

Tape, pressure sensitive, rubber and cork composition, per MIL-T-6841A, 1/32, or 1/16 inch thick, width as required in 1/4 inch increments.

Armstrong Cork Co.; Lancaster, Pa.
"DK-153"

3.1.5 Tying Material

a. Braid, flat woven, .0125 ± .0030 inch thick and approximately 3/32 inch wide, color white or tan, unwaxed, mildew resistance effectiveness per MIL-T-713, and 48 pound minimum breaking strength.

3.1.5 a. (Continued)

(1) Western Filament Corp.; Glendale, Calif.

1 "No. 17-D" (Dacron)

(2) Hemingway & Bartlett Mfg. Co.; New York, N.Y.

1 "Dacron Flat Braided Lacing Tape G.E. Finish"

(3) Eon Corporation; Los Angeles, Calif.

(a) 1 Airtex #417X (Dacron)

(b) 1 Airtex #217 (Dacron)

(4) Gudebrod Bros. Silk Co. Inc.; Philadelphia, Pa.

1 Dacron Stur-D-Lace H "18DH"

b. Braid, flat woven, "Dacron", .0125 ± .003 inch thick and approximately 3/32 inch wide, vinyl coated, color black, end-fray resistant; including mildew proofing effectiveness and 50 pound average breaking strength in accordance with MIL-T-713A.

(1) Eon Corporation; Los Angeles, Calif.
"Airtex 217, Class 2, Black"

(2) Gudebrod Bros. Silk Co. Inc.; Philadelphia, Pa.
"Fyr-Lace R, Style 18DR, Black"

3.1.6 Talcum Powder

a. Talcum Powder No. 325

Van Waters & Rogers; Seattle, Washington

3.2 TYPE II MATERIALS

3.2.1 Sleeving, Insulating, Heat-Shrinkable

1 a. Sleeving (heat-shrinkable), insulating, irradiated polyolefin, opaque colors as required, sizes per applicable standard (MIL-I-23053).

(1) Material may be obtained from:

Raychem Inc.; Redwood City, California
"Thermofit CRN"

3.3 TYPE IV MATERIALS

3.3.1 Sleeving, Insulating, Heat-Shrinkable

[1] Sleeving, heat-shrinkable, Polytetrafluoroethylene, (TFE "Teflon") natural color, sizes as listed below:

Raychem, Inc.; Redwood City, California
"Thermofit TFE"

Size	Max. I.D. as Supplied (In.)	Recovered I.D., (In.)	Size	Max. I.D. as Supplied (In.)	Recovered I.D. (In.)
30	.030	.022	14	.121	.078
28	.035	.025	12	.153	.096
26	.040	.028	10	.191	.116
24	.050	.032	8	.240	.144
22	.055	.037	6	.302	.178
20	.060	.044	4	.370	.224
18	.076	.052	2	.430	.278
16	.093	.063	0	.470	.347

Note: Use on high temperature wire and parts only.

3.3.2 Sleeving, Insulating

a. Sleeving; insulating, fiberglass, silicone rubber covered, fungus resistant treated, white color, per specification MIL-I-18057, (200°C, 8000V minimum average dielectric strength), ASG sizes 24 to 1/0, and 3/8, 7/16, 1/2, and 5/8 inch ID.

(1) Bentley Harris Mfg. Co.; Conshohocken, Pa.
"Ben-Har 1151"

(2) 3M Co., Irvington Division; Freehold, N.J.

Note: This material limited to procurement only when material per a(1) is unavailable.

"Irvington 411"

[1] b. Tubing, insulating, Polytetrafluoroethylene (TFE "Teflon"), nonrigid per MIL-I-22129, tubing I.D. sizes AGW 0 thru 30, and additional sizes as follows:

Note: This material may be used only when specified on Engineering drawings.

3.3.2 b. (Continued)

Nominal ID (In.)	Wall Thickness (In.)
3/8	.025 ± .006
7/16	.025 ± .006
1/2	.025 ± .006
9/16	.025 ± .006
5/8	.030 ± .006
3/4	.035 ± .008
7/8	.035 ± .008
1	.035 ± .008

c. Tubing; nonrigid, constructed of spirally welded extruded Polytetrafluoroethylene (TFE "Teflon") tape, per AMS 3653, red, minimum breakdown strength 5000 volts r.m.s., wall thickness .010 ± .002, AWG sizes 8, 4, 2, 0, and 3/8, 1/2 inch ID.

Hitemp Wires, Inc.; Mineola, N.Y.

1 "Nonrigid Temprene Teflon Tubing"

Note: This material may be used only when specified on Engineering drawings.

3.3.3 Strip, Protective

a. Strip (or film); Polytetrafluoroethylene, (TFE "Teflon"), unsupported, skived, virgin or reprocessed, natural or blue color, .005, .010, .015, or .020 thick and width as required in 1/4 inch increments.

(1) Continental Diamond Fiber Co.; Newark, Del.

1 "Unsupported 'Teflon'; Skived Strip"

(2) W. S. Shamban & Co.; Culver City, Calif.

1 "Kelon-T; Skived Strip"

(3) Raybestos-Manhattan, Inc.; Mannheim, Pa.

1 "R/M 829; Skived Strip"

3.3.4 Tape, Insulating

a. Tape, Polytetrafluoroethylene (TFE "Teflon"), pressure sensitive thermosetting adhesive, per MIL-T-23594, width as required in 1/4 inch increments, nominal overall thickness .0065 inch (.005 inch backing).

(1) 3M Co.; St. Paul, Minn.

2 "Scotch #61"

3.3.4 a. (Continued)

(2) Permacel; New Brunswick, New Jersey

2 "P-421"

(3) Connecticut Hard Rubber Co.; New Haven, Conn.

2 Temp-R-Tape Type "TV"

3.3.5 Tape, Protective

a. Tape, Polytetrafluoroethylene (TFE "Teflon"), glass supported, pressure sensitive thermosetting adhesive, width as required in 1/4 inch increments and nominal overall thickness aslisted.

(1) 3M Co.; St. Paul, Minn.

2 "Scotch #64" (.0065 thick)

(2) Permacel; New Brunswick, N.J.

2 "ET3758" (.005 thick)

(3) Connecticut Hard Rubber Co.; New Haven, Conn.

2 "CHR-A-2005" (.005 thick)

3.3.6 Tying Material

a. Braid; flat woven, fiberglass, "Teflon" coated, approximately 1/8 inch wide x 1/64 inch thick, and minimum breaking strength 90 pounds.

(1) Bentley Harris Mfg. Co.; Conshohocken, Pa.

1 "TG40"

(2) Dodge Fibers Corp.; Hoosick Falls, N.Y.

1 "E775-303" (Formerly TB-303)

b. Braid, flat woven, fiberglass, "Teflon" coated, approximately 5/64 inch wide x 1/64 inch thick and minimum breaking strength 45 pounds.

(1) Bentley Harris Mfg. Co.; Conshohocken, Pa.

1 "TG25"

(2) Dodge Fibers Corp.; Hoosick Falls, N.Y.

1 "E775-476" (Formerly TB-476)

3.4 MATERIALS NOT CLASSIFIED BY 'TYPE'

3.4.1 Thinner

Thinner; lacquer, per TT-T-266.

3.4.2 Varnish

a. Varnish, Nylon

(1) Nycote Type 88 with Type 88 accelerator (mix 5.7 parts accelerator with 100 parts base).

(2) Nycote Type 4-30

Nycote Laboratories
15002 Delano Street
Van Nuys, Calif.

4.0 DEFINITIONS

a. Breakout - A "breakout" refers to the point where cables depart from a cable bundle group.

b. Bundle - A cable "bundle" is a number of cables routed together and bound by bundle ties.

c. Group - A cable "group" is a number of cables tied together and routed to a single item or set of equipment.

d. Junction Shell - A cable bundle support fixture used to support bundles entering an electrical junction box. The fixture is similar to a flange mounting connector endbell with a cable clamp. Connector cable clamping requirements generally apply to junction shell clamping.

5.0 MANUFACTURING CONTROL

a. Form cables and bundles so as to minimize stress on cables and connections due to cable bends and clamping during installation. Forming may be accomplished by fabricating cable harnesses on form boards.

b. During fabrication and handling of cable assemblies, care shall be taken to prevent stresses or strains from being placed on terminations or connector contacts. Provide bench clamps or other necessary support when forming wires.

5.1 CABLE GROUPS AND BUNDLES

5.1.1 Binding Cables Into Groups and Bundles

a. Identify cabling in accordance with Appendix B-1.

5.1.1 (Continued)

b. Untangle wires as much as practicable before tying them into groups. Lay wire groups as parallel as practicable before tying into bundles. Crossed wires under bundle clamps are <u>not</u> acceptable.

c. Tie wire groups and bundles with tying material (3.1.5, 3.3.6) using a clove hitch and square knot as shown in Figure B-2-1. Tying cord may be doubled when wire groups or bundles exceed 1-1/2 inches in diameter.

(1) Before tying the square knot, cinch the clove hitch firmly in place by pulling the free ends of string in opposite directions while rotating them 90° to 180° about the hitch so they twist beneath it and are held in place. Do not stress or deform wire or cable insulation by overtightening the clove hitch.

(2) Tie the square knot tightly over the clove hitch and cut off free ends to a length of 1/4 to 1/2 inch.

FIGURE B-2-1

(3) For wiring on which ties tend to slip, an optional tie may be made by passing an initial loop through the bundle prior to making clove hitch as shown in Figure B-2-2. Tighten clove hitch on opposite side of bundle from the initial loop. Tie a square knot over the clove hitch (see Figure 1)

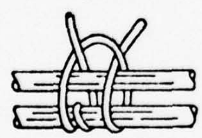


FIGURE B-2-2

d. In restricted areas, the modified clove hitch and square knot shown in Figure B-2-3 may be used as an optional tie for tying cable groups. Follow the procedure in c(1) and (2) above to secure the tie.

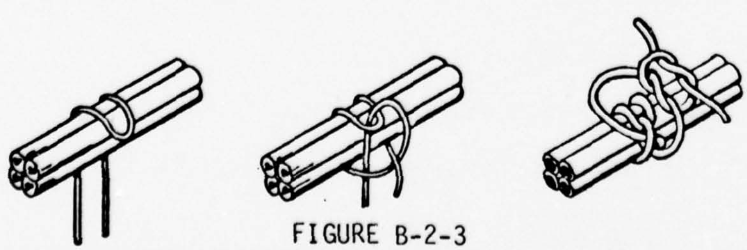


FIGURE B-2-3

SIZE	CODE IDENT. NO.	
A	81205	D180-24693-2
SCALE	REV	SHEET 29

5.1.1 (Continued)

e. Minimize fraying of fiberglass tying braids (3.3.6) by cutting tied ends using very sharp cutting tools. A small amount of nylon varnish (3.4.2) may also be applied on braid ends and knots if necessary to prevent fraying or loosening.

5.1.2 Spacing Ties for Bundle Support

a. Except as provided in 5.1.3, space ties on cable groups and bundles a minimum of 8 inches and a maximum of 12 inches apart except as follows:

(1) Tie as necessary to provide adequate support at bends, breakouts, and locations shere cable groups or bundles are adjacent to moving parts.

(2) Tie cables together in junction or terminal boxes only as required for support to facilitate removal of cabling and equipment.

(3) Tie groups and bundles such that support is not derived from terminals.

(4) When cable groups are tied within a bundle, the ties on the individual groups may be spaced a maximum of 30 inches.

(5) Space ties a maximum of 30 inches on groups and bundles installed in raceways.

(6) Use the minimum number of ties necessary to adequately support the groups or bundles as specified herein.

b. Assemble cables in conduit or insulating tubing such that they are untangled and parallel as much as practicable. Cables in conduit or insulating tubing shall not be tied together. Talcum (3.1.7) may be used as a lubricant on cables and tubing.

c. All temporary ties placed on cable bundles to facilitate handling or storage must be removed during or prior to bundle installations.

5.1.3 Tying of Equipment Internal Wiring

a. Stationary groups and bundles contained within ground support equipment consoles, cabinets, and components may be bound together by continuous lacing as an optional method to spot tying per 5.1.1.

(1) Using tying braid (3.1.5b), start the lacing by making a tie per Figure B-2-1. Cut off only the short end after making the knot.

(2) Make a continuous lacing using a series of locking stitches as shown in Figure B-2-4.

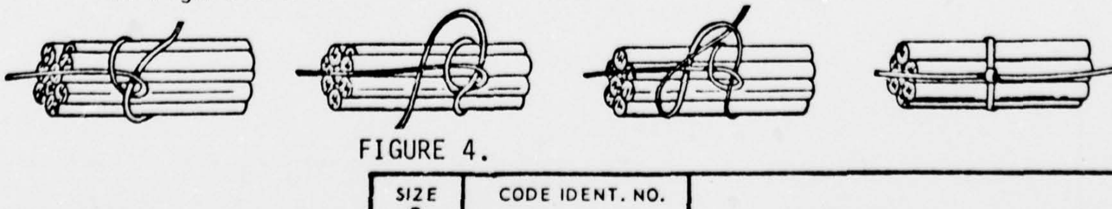


FIGURE 4.

5.1.3 a. (Continued)

(3) Apply continuous lacing with the appropriate interval between stitches per Figure B-2-5, except that a stitch may also be provided adjacent to each side of a cable breakout.

D (Inches)	L (Inches)
Less than 1/2	3/4 ± 3/16
1/2 to 1	1-1/2 ± 3/8
More than 1	2 ± 7/16

Note: Two successive intervals of stitching shall not differ by more than 20% of the larger interval.

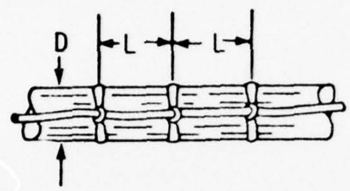


FIGURE B-2-5

b. Where spot ties per 5.1.1 are used on internal wiring of ground support equipment, space ties a minimum of 3 inches and a maximum of 6 inches apart.

5.2 PROTECTION OF BUNDLES

Where contact with adjoining flat or rounded surfaces may be possible but is otherwise unavoidable, protect groups and bundles from chafing or abrasion in accordance with the following:

a. Cover with shrinkable sleeving (3.2.1, 3.3.1) or non-shrinkable sleeving (3.1.1, 3.3.2). Tie non-shrinkable sleeving in place with bundle ties per 5.1.1 over each end of the sleeve.

b. Install shrinkable sleeving as follows:

(1) When practical, remove group or bundle ties prior to installing sleeves.

(2) Use a sleeve size that will fit permanently in place after shrinking. Ties may be omitted on tight fitting sleeves.

(3) Shrink sleeving using good standard practice.

(4) Shrinkable sleeving may be applied by heat-shrinking a minimum of three inches on each end for sleeves exceeding eight inches in length.

5.2 (Continued)

c. Provide drain holes in protective sleeves where more than 12 inches long. A pair of drain holes may be spaced diametrically opposite at 2 inch intervals with alternate pairs rotated 90^{o}, or they may be provided in groups of 4 holes evenly spaced around the sleeve circumference at 4 inch intervals. Make 1/8 inch holes in AWG 4 (nominal ID .208 inch) or larger sleeves and 1/16 inch holes in smaller sleeves.

Note: Drain holes are not required in close fitting shrinkable sleeves.

d. An alternate method to a, above, is to wrap the cable(s) with vinyl or teflon strip (3.1.2, 3.3.3). Completely cover starting end of strip on the first lap, then proceed with a one-half width spiral overlap. Secure wrapping with bundle ties at each end and at intervals of 8 inches maximum.

e. Protect cables and bundles from abrasion in uncushioned metal clamps by wrapping the cables with a minimum of two concentric wraps (.03 inch minimum buildup) of insulating or protective strip or tape (3.1.2, 3.1.3, 3.1.4, 3.3.3, 3.3.4, 3.3.5). Wrap the cables and tighten the clamp in such a manner that the jacket is not crushed or damaged and does not slip. Tightly wrap and hold the strip while tightening the clamp to prevent unwrapping.

f. Protect cables against abrasion at bundle supports and clamps by covering with sleeving or tape (3.1.1, 3.1.3, 3.2.1, 3.3.1, 3.3.2, 3.3.4, 3.3.5). Extend this protection 1 inch $\pm$ 1/8 on each side of the support. Install sleeving per a or b, above. Spirally wrap tape with a one-half width overlap, covering the starting end before lapping is begun, and spiral by wrapping the finishing end back under the support clamp or tie.

APPENDIX B-3

DETAILED INSTALLATION PROCEDURES

1.0 SCOPE

This section covers detailed steps in the installation of fiber optics cables and harnesses.

2.0 CONTENTS

3.0 REQUIREMENTS AND VERIFICATION

3.1 REQUIREMENTS

3.1.1 General

a. Protect unattached ends and connectors. Neatly coil the free ends of the bundles and stow to avoid damage.

b. Assemble cables in conduit or insulating tubing such that they are untangled and parallel to each other. Cables in conduit or insulating tubing must not be tied together.

c. All temporary ties or straps placed on cable bundles to facilitate handling or storage must be removed during or prior to installation.

NOTE: Exercise care to prevent damage to cables when removing ties or straps and to prevent cut straps or ties from dropping into aircraft components or equipment.

3.1.1 (Continued)

d. Smoothing and filling compound may be applied over projecting rivets, bolts, nuts, or other protrusions which present an abrading surface to adjacent cables.

e. Cabling shall not be encased with tape or sleeve unless specified on the bundle assembly or installation drawings. When shrinkable sleeving is specified to be shrunk, shrink from one end heating evenly until the other end of the tube is reached. Move the heat gun evenly without overheating the cable.

f. At shock mounted equipment, all cables from each connector may be tied together, but the cables from one connector shall not be tied to the cables from another connector between the unit and the first clamp.

3.1.2 Cable Slack

a. Distribute slack evenly throughout the length of the bundle. Install cable bundles as shown in Figure B-3-1.

Where installation location markers are used, distribute slack evenly between the markers.

b. In applicable areas make certain that there is adequate slack to meet the following requirements:

(1) Replacement of terminations at least three times.

NOTE: Where space permits, include the excess cable length for retermination of connectors in the form of a drip loop. Otherwise include the length in the first six feet leading to the connector or other terminations.

(2) Movement of hinged joints.

(3) Removal of face-mounted equipment, where other means of access is not provided.

(4) Coupling and uncoupling of connectors.

(5) Special maintenance and service applications specified on the engineering drawing (e.g., to permit ample shifting of equipment while still in the aircraft, for the purpose of realignment, removal of dust covers, servicing, tuning and changing components or assemblies).

(6) Prevention of strain on cables to shock-mounted equipment.

(7) Provision of drip loops.

(8) Adequate cabling movement at bulkheads and on long straight cable runs to compensate for the expansion and contraction of the aircraft structure induced by climate extremes.

3.1.2 (Continued)

b. (Continued)

(9) Prevent mechanical strain on cables, terminals, junctions, and supports.

c. Make sure that there is at least three inches supported separation between cabling and fluid (except water) lines, oxygen lines, control cables, and their equipment.

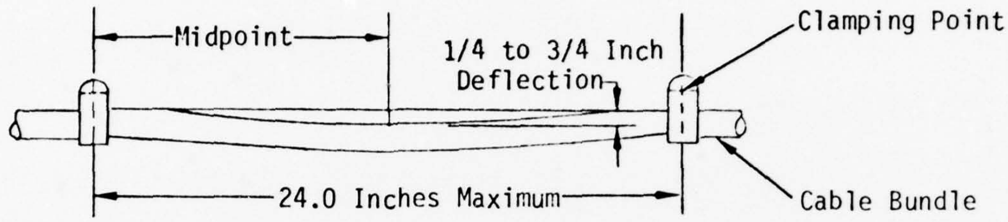


FIGURE B-3-1. SLACK IN CABLING

3.1.3 Drip Loops

a. To prevent fluids from entering junction boxes, connectors, or other enclosed items, provide a drip loop in the cable or bundle just before it enters the item of equipment.

b. Locate drip loops so that fluid will not drip on other equipment.

c. Carefully seal around the cable (except on potted and moisture proof connectors) at the point of entry with a coating compound, required by Engineering drawing.

d. Drip loops are not required on cable or bundles that terminate in a potted connector.

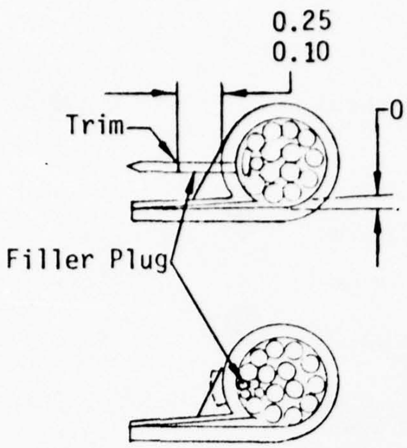
3.1.4 Bend Radius

Use a minimum bend radius of ten times the cable or bundle diameter. In restricted spaces the bend radius may be a minimum of six times the outside diameter or 1-1/2 inches, whichever is greater.

3.1.5 Bundle and Cable Support

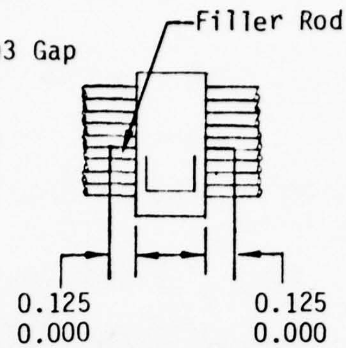
Cable clamps must be compatible with the area where the cable is installed and must be the smallest which will hold the bundle without crushing or pinching the cable. The clamps must conform with the following installation instructions.

a. Clamp wire bundles and cables (including twisted cables) firmly at all supports. Do not allow cables to cross each other under cable bundle clamps.



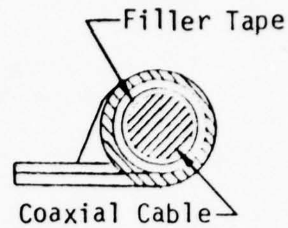
INSTALLATION OF FILLER PLUGS

Figure B-3-2



INSTALLATION OF FILLER ROD

Figure B-3-3



INSTALLATION OF FILLER TAPE

Figure B-3-4

3.1.5 (Continued)

b. If the bundle diameter is such that none of available clamp sizes will firmly grip the bundle, use one of the following methods to build up the bundle diameter:

(1) For all applications except in fuel cells or with coaxial cable, use filler plugs, installed according to Figure B-3-3, or filler rods, installed according to Figure B-3-3.

(2) Filler tape shall be installed to Figure B-3-4, as required.

c. When contact exists, or is possible, between crossing wire groups or bundles, tie the groups or bundles together.

Critical bundles requiring isolation as specified by Engineering drawing diagrams must not be tied to other groups or bundles.

d. Do not install clamps in the bends of the bundle unless the radius of bend exceeds six inches.

e. Use clamp sizes which do not deform the cable.

f. Nylon clamps may be installed with a gap of .03 inches as shown in Figure B-3-2.

g. Install wire groups or bundles on tombstone bundle supports as follows:

(1) Distribute the wires around the cross as evenly as possible.

(2) Double the cord or braid used for tying wire bundles over 3/4 inch in diameter.

3.1.5 g. (Continued)

(3) Tie bundle as shown in Figures B-3-5 and B-3-6. Make the clove hitch snug and the knot tight.

(4) Leave free ends of the knot 3/8 ± 1/8 inch long.

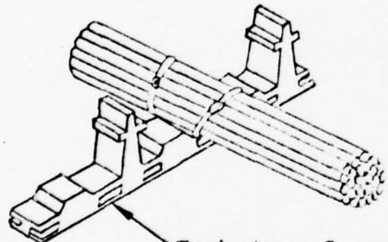
NOTE: Never bind a tie so tightly it cuts or penetrates the insulation.

h. Do not use ties, straps, or tapes for primary supports.

i. When cable groups are bundled and routed together, do not destroy the identity of the individual cable groups, nor remove their ties.

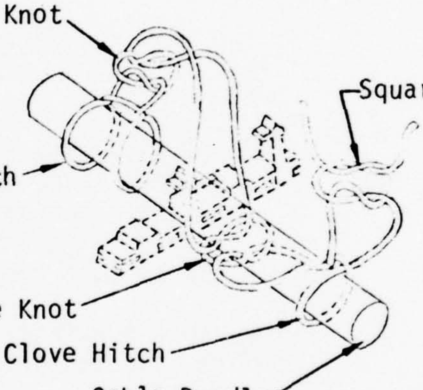
j. Do not use continuous lacing.

k. Do not tie bundles of two or more connectors together until after their first common clamping point.



SECURING WIRE BUNDLES TOMBSTONE SUPPORTS

Figure B-3-5



DETAIL METHOD OF SECURING BUNDLES TO SUPPORTS

Figure B-3-6

3.1.6 Coupling of Connectors

a. Make certain that plugs and receptacles are properly mated and fully coupled.

b. On threaded coupling connectors that do not require safety wiring, tighten coupling nuts by hand, then slightly beyond hand tight (1/8 turn maximum) with tool AT 508K (Aircraft Tools, Inc., Los Angeles, California).

On connectors that do require safety wiring, tighten coupling nuts <u>by hand only</u> before installing lock-wiring.

3.1.6 (Continued)

c. Engage bayonet-type and ball-lock connectors only by hand. Make certain coupling rigs are fully engaged and in the completely locked position.

d. Check for tightness by hand and only in the direction of coupling. On connectors that require safety wiring, check for tightness only prior to safety wiring.

e. Engage connectors with jackscrew-type coupling as follows:

(1) Before threading the jackscrews into the jacksockets, seat them tightly against each other.

(2) Use care, turning each screw one-half turn at a time alternately by hand until the pin contacts begin to enter the socket contacts.

(3) Continue tightening each screw by one or two turns alternately until the connectors are fully mated.

3.1.7 Modification of Harnesses

When a cable or cables must be replaced or added to a completed bundle as a result of a change or a Materials Review Board action, accomplish the modification as follows:

a. Identify cable or cables by appropriate markings.

b. Replacement and added cable(s) may be installed by either threading and pulling the cable(s) through the bundle ties and support clamps or by the procedure outlined below.

(1) Tie the added cable(s) to the exterior of the bundle with ties in accordance with Appendix B-2. If the bundle is installed, ties are required between clamps only and at approximately one foot intervals.

(2) These cables need not be installed under existing ties, tapes, markers, etc. on the parent bundle. However, they must be installed within all support clamps of the parent bundle.

3.1.8 Test of Cabling

Optical power transmission checks are the responsibility of the Manufacturing Department except when otherwise specified on the Engineering drawing.

3.1.9 Protection of Terminations

If cabling is to remain unconnected in the delivered product installation, protect the unconnected ends as follows:

a. Insulate unattached cable ends with tape or shrink sleeving.

b. Protect installed uncoupled connectors with dust caps.

3.1.9 (Continued)

c. Stow the cabling so that contaminants cannot fall or drain into the protective covers.

3.2 VERIFICATION

3.2.1 In-Process Surveillance

a. Assure that only approved materials are used to satisfy the requirements of this specification.

b. Assure that temperature, fluid, and vibration restrictions are observed.

c. Assure that terminals, splices, connectors, and wires are properly installed, supported, and protected.

d. Assure that circuits are properly tested as specified on the Engineering drawing before application of aircraft power.

APPENDIX B-4

MARKING OF FIBER OPTICS CABLING

1.0 SCOPE

The purpose of this document is to provide the methods and requirements for marking fiber optic cables and bundles.

2.0 CONTENTS

3.0 MATERIALS CONTROL

NOTE: These are suggested sources. Where competing equal suppliers are available, use is permissible.

a. Agent, Parting, Silicone Grease, 400°F minimum decomposition temperature

Dow Corning "High Vacuum Grease"
Dow Corning Corporation

b. Adhesive

(1) Gaco N-29 Cold Bond and N-39 Accelerator (BAC 5010, Type 53)
Gates Engineering Company

(2) PR1527M with PR1523M, Primer (BMS 8-81) Products Research Corporation

c. Braid, flat woven, synthetic fiber, 0.0125 ± 0.0030 inch thick and 0.070 to 0.100 inch wide, color white or tan, unwaxed. Mildew resistance effectiveness in accordance with MIL-T-43435 and 48 pounds minimum breaking strength.

(1) Airtex 417X (Dacron), Associated Suppliers Co.

(2) No. 17D (Dacron), Western Fishing Line Company

(3) Dacron Flat Braided Lacing Tape, G.E. Finish
Heminway and Bartlett Manufacturing Company

d. Braid, flat woven, fiberglass, Teflon coated, approximately 5/64 inch wide by 1/64 inch thick, minimum breaking strength 45 pounds.

(1) #TG-30, Bentley Harris Manufacturing Co.

(2) #TG-476, Dodge Fibers Corporation

e. Coating, Spray, Protective, Removable, Spraylat #SC1071, Spraylat Corporation

f. Coating, Spray, Protective, Nonremoveable

(1) Acrylic Aerosol Spray

Tartan #91-1, Rudd Paint and Varnish Company
Krylon #1303, Krylon Incorporated

(2) Varnish, Moisture, and Fungus Proof, IAW MIL-V-173
Sprayon #608, Sprayon Products, Incorporated

3.0 (Continued)

g. Foil, Printing 1-1/2 and 3 inch widths

(1) Kingsley Stamping Machine Co.

(a)	K-36	General Purpose
(b)	K-46	Nylon
(c)	KFP-16 Black	Surface Treated Teflon
(d)	K-289 White	Polyethylene

(2) M. Swift and Sons, Incorporated

(a)	C20114 Black	Surface Treated Teflon & General Purpose
(b)	C20118 Black	Surface Treated Teflon & General Purpose
(c)	C20206 White	General Purpose
(d)	C20110 Black	Nylon

(3) Howmet Corporation, Roll Leaf Division

(a)	5821 Black	General Purpose
(b)	WW99 Black	Surface Treated Teflon

h. Ink, Marking

(1) #73X-NW, Black, Independent Ink, Incorporated

(2) W. E. 42 Paste Ink, White, General Printing Ink, Incorporated

i. Paper, Liner, Creped-Kraft, width as required

(1) No. RP360, 3M Company

(2) Permacel E13734, Permacel Division, Johnson and Johnson, Inc.

j. Ribbon, Printing

(1) IBM 143341 (for IBM 407 Printer)

(2) IBM 1403-OCR No. 424325 Black (for IBM 1403 Printer)

(3) IBM Cartridge #1136108 (for IBM Selectric typewriter)

(4) H&M Gold Star #37 (heavy black) (for IBM Selectric Typewriter)

(5) Singer (Friden) #4003030 (for Singer (Friden) Flexowriter typewriter)

3.0 (Continued)

k. Sleeving, insulating, fiberglass, silicone rubber covered, fungus resistant treated, color white, Class H-B-1 meeting performance requirements of MIL-I-3190, in standard sizes as required.

(1) Turbo 117, Brand-Rex Division, American Enka Corp.

(2) Class H-B-1 Type SR-9, Varflex Corp.

m. Sleeving, identification, fiberglass, Kel-F suspensoid treated, in standard sizes as required, Gencote 125C, General Plastics Corp.

n. Sleeving, insulation, electrical, flexible in accordance with MIL-I-7444, Type III, Class 2, color yellow

o. Strip, polyvinyl alcohol film, perforated, 17/64 or 3/4 inch spacing on diagonal, 3 mil thick x 3/4 or 1 inch width.
Reynolds Metals, Plastic Division

p. Strip, plastic vinyl (PVC), transparent, flexible (material same as for sleeving in accordance with MIL-I-7444), 0.020 $\pm$ 0.0015 inch thick, 3/4 or 1 inch widths.
Strip-Plastic No. CT93, Borden Co., Chemical Division, Resinita Department

q. Strip, plastic, polyvinyl chloride, black opaque, nonrigid, Type F, form Ts, Class, Category I, in accordance with MIL-I-631, 0.020 $\pm$ 0.0015 inch thick, width as required (tolerance $\pm$ 5 percent) in 1/4 inch increments.
Plymouth Rubber Company

r. Strip, silicone rubber, self bonding, 0.020 inch thick x 1 inch width.
Permacel 2650
Permacel Division, Johnson & Johnson, Incorporated

s. Tape, Electrical Polyvinylchloride, pressure sensitive, yellow or black, opaque, 0.007 $\pm$ 0.001 inch thick, width as required (tolerance 0.06 inch) in 1/4 inch increments.

(1) Permacel No. 29 (specify yellow or black)
Permacel Division, Johnson & Johnson, Incorporated

(2) X-1235, Prebacked (specify yellow - not available in black)- 3M Co.

t. Tape electrical, glass cloth-backed, white, pressure sensitive, according to MIL-I-19166 widths as required in 1/4 inch increments.
Mystic Brand #7000, Mystic Tape, Inc.

u. Tape Masking, creped, various widths - Purchased from any available source.

v. Tape, paper backed cloth, vinyl impregnated
B-500 + specify color, width, and type of backing, W. H. Brady Company

3.0 (Continued)

w. Tape, polyvinylchloride, pressure sensitive, red, opaque, width as required in 1/4 inch increments, Parmacel No. P-32, Permacel Division, Johnson & Johnson, Inc.

x. Tubing, shrinkable, heat reactive plastic

y. Tubing, shrinkable, heat reactive plastic according to BMS 1-41, Type 5, sizes according to BACT63B

4.0 FACILITIES CONTROL

The printing devices listed below are suggested. Equivalent models or devices may be used provided all marking requirements are met.

a. Embossing Machines

(1) Kingsley Wire Marking Machine Model KW-7 for sleeve and tube marking.

(2) Kingsley Wire Marking Machine Model AW3.

(3) Kingsley Wire Marking Machine Model AWIV.

(4) Kingsley Wire Marking Machine Model AWIVC.

(5) TAB Wire Marking Machine Model MA-200.

b. Cold Imprinting Machines

(1) Singer (Friden) Automatic Typewriter, Model 2201 Flexowriter

(2) IBM Selectric

(3) IBM 407 and 1403

5.0 MANUFACTURING CONTROL

5.1 GENERAL REQUIREMENTS

a. All marking shall be of sufficient size and definition to be legible and of a permanent nature.

b. The characterisitcs of the wire or cable shall not be impaired by the use of any marking device or by the removal of marking when required.

c. Metallic markers or bands shall not be used for identification.

d. The information for identification, mate-with, and P.I. markers shall be obtained from the Engineering drawings.

e. Identification of wiring in furnished equipment shall not be altered unless authorized by the procuring activity.

5.1 (Continued)

f. Required marking on cables and bundles attached to connector plugs and receptacles shall be applied outside potting material or adapter clamps. The marking shall be outside any sealant or wrapping under the cable adapter clamp.

g. Wires in permanently concealed runs shall be identified at the entrance and exit points of the run and at any additional points specified by the drawing.

h. Where space permits, markings on cables and harnesses shall not conceal other markers.

i. All ordnance markings shall be red, and marked in white with the work "ORDNANCE".

j. Make every effort to locate terminating point identification so that ties, clamps, supporting devices, shielding, and terminals do not have to be removed, or the cable twisted in order to read the identification. Terminating point identification which falls on the underside of the wire or beneath a tie are acceptable if they can be easily read by the use of an inspection mirror or by moving the tie.

k. Heat shrinkable tubing installation and size selection shall be performed in accordance with good standard procedure.

5.2 INDIVIDUAL CABLE MARKING

5.2.1 Selection of Marking Method

5.2.1.1 Identification Markers (Direct Imprinting)

a. Use a hot embossing machine to mark cable surfaces which provide good contrast with the most suitable marking foil from the materials list, or, if ink jet marker is available, the most suitable ink identified in the materials list or by the supplier.

5.2.1.2 Identification Markers (Imprinted Tubing or Sleeves)

a. Cables that provide poor contrast when imprinted with marking foil, and cables which will not accept or retain a clear machine imprinted identification shall be identified as follows:

(1) Use yellow heat-shrinkable tubing (3.0x) to identify wiring contained in areas with temperatures below 200°F which is not directly imprinted.

(2) Sleeving may be used as an option in place of heat-shrinkable tubing for wire identification. The sleeve shall have the smallest practicable diameter which will fit over the wire.

5.2.1.2 a. (Continued)

(3) When specified on the Engineering drawing, for use in high temperature areas (above 200°F), markers shall be made from sleeving.

b. Identification (number and color code) for individual cables contained in jacketed bundles shall be installed on the cable outer covering using heat-shrinkable tubing or imprinted sleeves. The color coding as shown below shall be spaced so that it does not appear as an integral part of the cable number.

Blu - Blue	Yel - Yellow	Grn - Green
Brn - Brown	Red - Red	Orn - Orange
Blk - Black	Whi - White	
Gra - Gray	Vio - Violet	

When a multiconductor cable is broken out into individual branches which are 12 inches or shorter the cable marking shall be sufficient. Individual branches longer than 12 inches shall be marked in addition to the normal cable marking.

c. Split identification sleeves may be used to replace defective sleeves. Split sleeves may also be used to identify wires at terminating points.

5.2.1.3 Identification Markers (Imprinted Adhesive Tape)

When specified on the Engineering drawing, paper-backed vinyl impregnated cloth tape shall be used to identify electric wiring.

5.2.1.4 Ordnance Markers

Ordnance markers shall be made from red heat-shrinkable tubing marked in white with the word "ORDNANCE".

5.2.2 Location of Marking

5.2.2.1 Identification Markers

a. These markings shall be located at intervals not greater than three inches except as noted in b. and c. below.

b. When specified on the Engineering drawing, for electronic equipment and interconnects in aircraft or missiles, the markings shall be within three inches of each end and at intervals not greater than 15 inches between end marks.

c. Lengths less than three inches long shall not require marking.

5.2.2.2 Ordnance Markers

Ordnance markers shall be located as near as possible to the wire ends and at intervals no greater than 15 inches throughout the cable length.

5.2.3 Marking Application

5.2.3.1 Direct Imprinting

a. Select the size of type which is appropriate for the cable to be marked. The curvature of the type face should approximate the surface curvature (See Figure B-4-1).

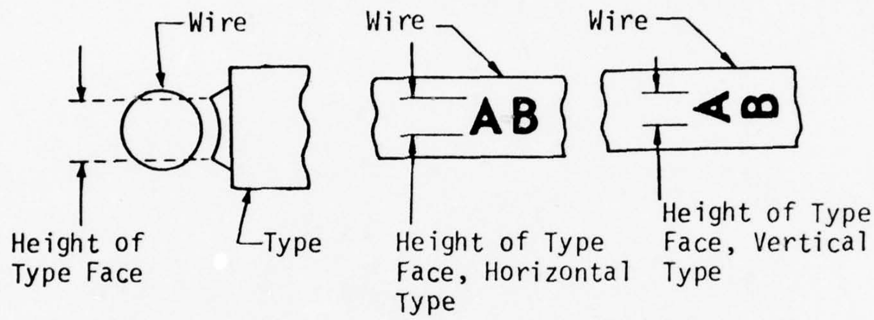


FIGURE B-4-1

b. Table B-4-1 gives the ranges of type face heights for corresponding diameters which will produce the optimum mark with the least penetration of the type into the outer surface.

TABLE B-4-1

WIRE SIZE AND TYPE FACE HEIGHT

Kingsley Type		Wire O.D.		Trojan Type	
Type Height	Identification Number	Minimum	Maximum	Type Height	Identification Number
0.025	VC-24	0.035	0.025	0.025	Vertical Type AP204 [1]
0.025	VC-24	0.040	0.061	0.040	AP104
0.050	DS	0.052	0.076	0.050	AP105
1/16	RS	0.068	0.096	0.050	AP105
1/16	RS	0.075	0.106	0.070	AP106 [2]
5/64	S	0.095	0.165	0.080	AP108 [3]
7/64	L	0.162	And Larger	0.109	AP110 [4]

[1] AP104 (Optional)
[2] AP105 (Optional)
[3] AP105 or AP106 (Optional)
[4] AP105, AP106, or AP108 (Optional)

SIZE	CODE IDENT. NO.		
A	81205	D180-24693-2	
SCALE	REV	SHEET 47	

5.2.3.1 (Continued)

c. To prevent uneven depth marking, make sure that type faces are clean and that all characters are set in the same plane. Plated and unplated type may be of different lengths and should not be used together.

d. Select a marking foil as specified in the materials list for the jacket type being marked.

e. Adjust machine pressure, temperature, and dwell time to provide markings for best legibility. Markings shall be considered permanent if legible after being subjected to the test specified in the test methods.

5.2.3.2 Imprinting Tubing and Sleeving

a. Printing on heat shrinkable tubing and sleeving shall be accomplished by hot embossing as on wire insulation. Printing shall be along the length of the tubing or sleeving. Heat shrinkable tubing on bandolier or with similar type backing in tubing may also be printed with a Friden automatic typewriter, modified as necessary, and using printing ribbon.

CAUTION: Exercise care not to smear markings on tubing immediately after printing with Friden typewriter. Printing is not permanent for up to 1/2 hour after typing.

b. In most cases flat-faced type will be used with a flat anvil. Very small size tubing or sleeving may be marked with curved face type and a wire guide if the marking requirement can be met.

c. For hot embossing, the imprinting type temperature shall be 400°F minimum (indicated temperature). Use printing foil specified in Table B-4-2.

TABLE B-4-2

HOT EMBOSSING FOIL

Tubing or Sleeving Type	Foil Type
3.0x.	3.0g.
3.0n.	3.0g.
3.0m.	3.0g.(1)(a) 3.0g.(2)(a) 3.0g.(2)(b)
3.0y.	3.0g.
3.0x. (Ordnance)	3.0g.(1)(d) 3.0g.(2)(c)

5.2.3.3 Imprinting Adhesive Tape

Print identification on the tape in accordance with 5.3.3.2.

5.3 WIRE HARNESS MARKING

5.3.1 Selection of Harness Marking Method

5.3.1.1 Identification Markers

Identification (part number) markers shall be as follows:

a. Use tape (3.0s., yellow) or heat-shrinkable tubing (3.0x., yellow).

b. When specified on Engineering drawing, for use in high temperature areas (above 200°F), markers shall be made from tape (3.0t.) or sleeving (3.0k. or 3.0m.).

5.3.1.2 Mate-With Markers

Connector mate-with markers shall be as follows:

a. Use tape (3.0s., yellow), sleeves (3.0n.), or heat-shrinkable tubing (3.0x., yellow).

b. When specified on Engineering drawing, for use in high temperature areas (above 200°F), markers shall be made of tape (3.0t.) or sleeving (3.0m.)

5.3.1.3 Production Illustration (P.I.) Markers

P.I. markers shall be made of tape (3.s., yellow) unless otherwise specified

5.3.1.4 Ordnance Markers

Ordnance markers shall be made from tape (3.0w., red), or heat-shrinkable tubing (3.0x., red) marked in white with the word "ORDNANCE".

5.3.2 Location of Harness Marking

5.3.2.1 Identification Markers

These markers shall be located as near as possible to each end of the wire harness, and at intervals no greater than 6 feet, throughout the length of the harness.

5.3.2.2 Mate-With Markers

These markers shall be placed on the connector or on the wire harness within 3 inches of the rear face of the connector grommet, but not close enough to cause misalignment of contacts due to pressure on wires.

5.3.2.3 Production Illustration (P.I. Markers)

These markers shall be located in accordance with Engineering drawings.

5.3.2.4 Ordnance Markers

These markers shall be located as near as possible to the ends of the wire harness and at intervals no greater than 15 inches throughout the length of the wire harness.

5.3.3 Marking Application

5.3.3.1 Imprinting Heat-Shrinkable Tubing and Sleeves

Imprinting heat-shrinkable tubing and sleeving shall be accomplished as specified in 5.2.3.2.

5.3.3.2 Imprinting Adhesive Tape

a. Tape which is not prebacked shall have the adhesive protected with backing paper (3.0i.) during this operation. Tape shall be marked by direct embossing or printed with an automatic typewriter (4.0b.) as follows:

(1) Direct Embossing - Apply marking using a hot stamping machine (4.0b.) with 1/8 inch high printing type and with type regulator set at approximately 450^{O}F. Use printing foil in accordance with Table B-4-3.

TABLE B-4-3

HOT EMBOSSING TAPE & FOIL

Tape	Ribbon
3.0s. (Yellow)	3.0g.(1)(a) 3.0g.(2)(b) 3.0g.(3)(a)
3.0s. (Black)	3.0g.(1)(d) 3.0g.(2)(c)
3.0w. (Red)	3.0g.(1)(d) 3.0g.(2)(c)

(2) Automatic Typewriter - Apply marking with an automatic typewriter using tape and ribbon in accordance with Table B-4-4

TABLE B-4-4

AUTOMATIC TYPEWRITER TAPE & RIBBON

Tape	Ribbon
3.0t.	3.0j.(3) 3.0j.(4)
3.0s. (Yellow)	3.0j.(3) 3.0j.(4) 3.0j.(5)

5.3.3.2 (Continued)

b. Print across the width of the tape. The printing shall be wholly contained on the tape.

c. The P.I. mark and the lettering on the marker must be printed symmetrically to the centerline of the tape in accordance with Figure 2.

d. Print the marking repetitively (except according to 5.3.3.2e.) on a continuous tape. Space between each marking shall be at least twice the line spacing but not to exceed 1-1/2 inches, however tape length shall be such as to accommodate at least two complete markings. See Figure B-4-2 for typical Marking Bands.

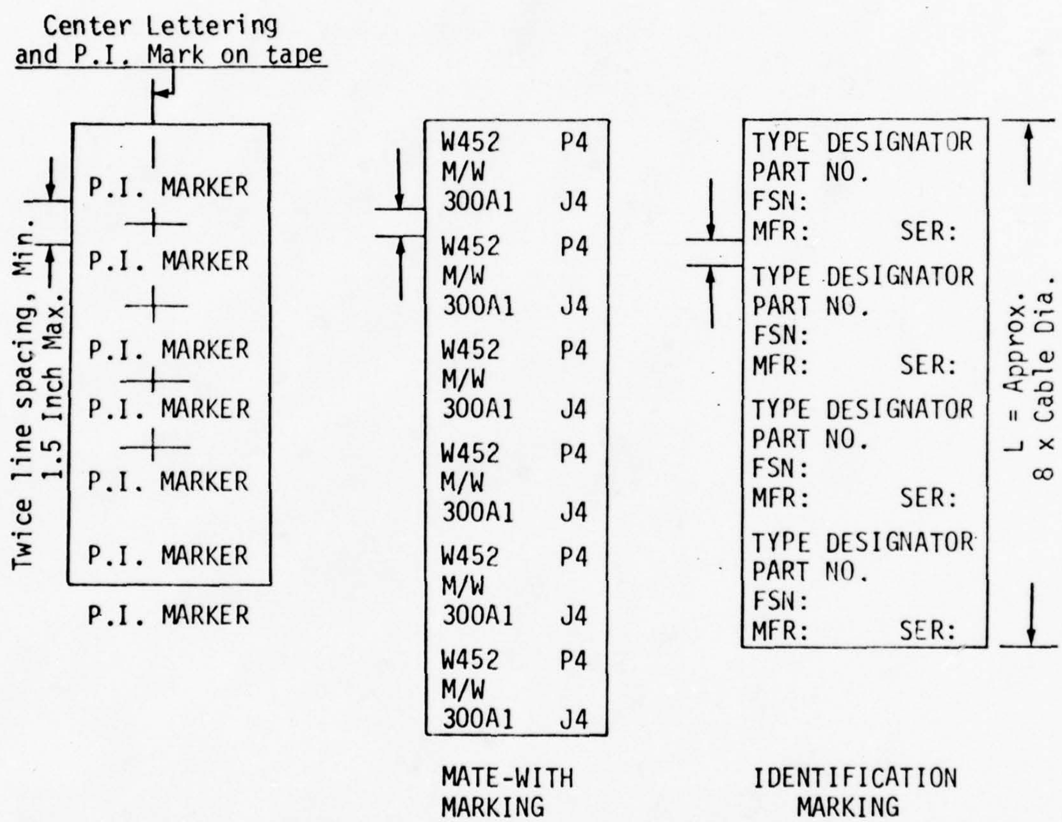
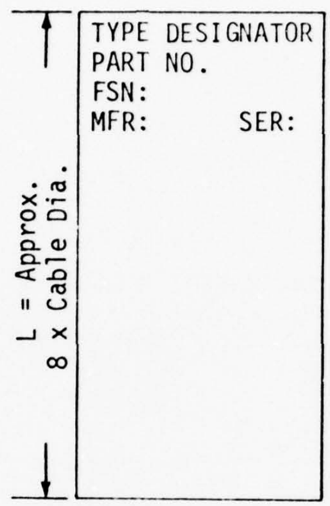


FIGURE B-4-2. TAPE MARKING BAND, REPETITIVELY PRINTED

5.3.3.2 (Continued)

e. On identification bands repetitive printing on the same band is not necessary if the cable or wire harness is long enough to require at least two identical identification bands, in accordance with 5.3.2.1 or 5.4.2.1. See Figure B-4-3.



IDENTIFICATION BAND
WITH SINGLE PRINTING

FIGURE B-4-3

f. Marking bands of tape must have the information printed repetitively, even if only one complete nomenclature can be read without unwrapping the tape. This assures at least two sources from which to reconstruct information from worn, one-of-a-kind cable bands. Mate-With Marking bands and P.I. Marker bands appear once only on each cable or wire harness regardless of length. Therefore, they must always be printed repetitively if marking tape is used, because the printing on tape is less permanent than hot stamped printing.

g. Cure markings on tapes printed with an automatic typewriter by one of the following methods.

   (1) Process marked tape through an infrared heating unit.

   (2) Apply heat from a 500°F rated air gun. Exposure shall be from one minute to five minutes maximum. Distance from the tape shall be 6 to 7 inches.

   (3) Apply a light coating of Acrylic Aerosol Spray (3.0f.(1)).

5.3.3.2 g. (3) (Continued)

CAUTION: Follow manufacturer's instructions printed on the container. The spray may not be used in electric wiring or part assembly areas.

h. Marking shall be considered permanent if it is legible after being subjected to the test specified in 5.6.1.

5.4 CABLE MARKING

5.4.1 Selection of Cable Marking

5.4.1.1 Jacketed Cables

Cables shall be marked using the applicable method indicated in Table B-4-5.

TABLE B-4-5

CABLE JACKET MARKING GUIDE

Marking Method / Jacket Material	Shrinkable Sleeve (3.0x.)	Tied-On Sleeve (3.0k.)	Adhesive Tape	Direct Embossing
Neoprene	2	Do Not Use	4	Do Not Use
Polyurethane	2	Do Not Use	4	Do Not Use
Polyvinylchloride (PVC)	2	1	3	Do Not Use
Polyethylene	1	2	3	2
Teflon	1	2	3	Do Not Use
Nylon	1	2	3	Do Not Use

1 Use this method unless otherwise specified on Engineering drawings.

2 Use this method only if specified on Engineering drawings.

3 Use this method (tape 3.0s., yellow) for rework on cables with damaged marking sleeves.

4 Use this method (tape 3.0s., black) only when specified on the Engineering drawings.

5.4.1.3 Polyurethane Connector Moldings

a. When specified on the Engineering drawing, polyurethane connector moldings shall be marked with white ink stamping with a clear acrylic overcoat.

b. When specified by Engineering drawing, adhesive patches per 5.4.3 may be applied to connector moldings.

5.4.1.4 Polyolefin Heat-Shrinkable Boots

When specified on the Engineering drawing, marking shall be applied to polyolefin heat-shrinkable boots by white ink stamping with overcoats of clear acrylic and abrasion resistant varnish.

5.4.1.5 Cadmium-Plated Connector Backshells and Fittings

When specified on the Engineering drawing, marking shall be applied to cadmium-plated connector rear hardware by black ink stamping with an acrylic overcoat.

5.4.2 Location of Bundle Marking

5.4.2.1 Identification Markers

a. On cables over six feet long, these markers shall be located as near as possible to each end of the cable jacket.

b. Cables six feet long, or shorter, shall be identified at the approximate center.

c. Breakouts of individual cables shall be marked as required in 5.2.1.2b.

5.4.2.2 Mate-With Markers

Mate-with markers shall be located on the connector or on the cable adjacent to the connector. When specified on the Engineering drawing, they shall be placed on the molding, boot, or backshell.

5.4.2.3 Production Illustration (P.I.) Markers

P.I. markers shall be located in accordance with Engineering drawings.

5.4.2.4 Ordnance Markers

Ordnance markers shall be located as near as possible to each end of the cable jacket and at intervals no greater than 15 inches throughout the length of the cable.

5.4.3 Marking Application

5.4.3.1 Printing on Adhesive Patches

This procedure describes the color transition marking of the green surface Hypalon laminate. Heated areas of the patch change from green to yellow producing a contrasting legible marking which is inherently permanent.

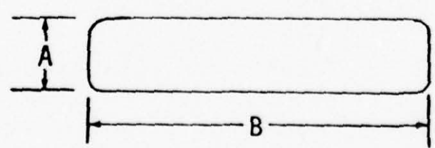
Preparation of Patch for Printing:

a. Spray or brush a thin layer of "spraylat" (3.0e.) on the rear (black side) of the laminate stock. Allow a minimum of 90 minutes drying time at normal room temperature before trimming the patch to size.

   CAUTION: Do not spray in electric wiring or part assembly area.

b. Cut the patch, after drying, to the dimensions shown in Figure 4, taking care not to delaminate the patch nor separate the "spraylat" coating from the patch. For patches requiring more than three lines of type or more than 20 characters and spaces per line, dimensions A and B may be increased proportionately. Minimum edge margin requirements of 5.4.3.1c must be maintained. Patch size tolerance is ± 1/4 inch.

Patch Type	Dim. "A" (Inches)	Dim. "B" (Inches)
Identification	3/4	3
Mate-With	3/4	3/4
	1/2	1 1/4
	3/4	1 1/4 or 3
P.I. Marker	3/4	1 1/4
Reference Designator	1/2	1/2



3/32 ± 1/32 Radius (Typical)

FIGURE 4. PATCH SIZES

5.4.3.2 Printing on Polyurethane Connector Moldings

Mark polyurethane connector moldings using method specified on Engineering drawing (adhesive patches or ink stamping).

a. Adhesive Patches

Apply marking to adhesive patches as specified in 5.4.3.1.

b. Ink Stamping

(1) Use rubber stamps with a character height of 1/8 to 1/2 inch. On small components, where size is a limiting factor, 1/16 inch character height may be used.

(2) Abrade the area to be marked with an aluminum oxide grit drum, disk, or rotary file.

(3) Clean surface to be printed with aliphatic naphtha. Wipe dry with clean material and then allow surface to air dry for ten minutes.

(4) Use white paste ink (3.0h.(2)) without thinning. Apply a small amount to a clean sheet of glass or metal and roll out to a smooth layer. Apply ink to the prepared area using rubber stamp.

(5) Air dry until tack-free and for an additional ten minutes.

(6) Overcoat marking with a light coat of acrylic spray, 3.0f.(1). When tack-free, apply an additional coat to achieve a glossy, continuous coating. Air dry for ten minutes.

CAUTION: Do not spray in electric wiring or part assembly area.

5.4.3.3 Printing on Polyolefin Heat-Shrinkable Boots

Mark polyolefin heat-shrinkable boots by ink stamping as follows when specified on Engineering drawings.

a. Use rubber stamps with a character height of 1/8 to 1/2 inch. On small components, where size is a limiting factor, 1/16 inch character height may be used.

b. Abrade the area to be marked with 400 grit abrasive paper.

c. Clean surface, apply markings, air dry, and overcoat with clean acrylic as specified in 5.4.3.3b.(3) through b.(6).

d. Overcoat clear acrylic with abrasion resistant varnish (3.0f.(2)).

5.4.3.4 Printing on Cadmium Plated Connectors Backshells and Fittings

Mark cadmium plated connector hardware by ink stamping as follows when specified on Engineering drawings.

a. Use rubber stamps with a character height of 1/8 to 1/2 inch. On small components, where size is a limiting factor, 1/16 inch character height may be used.

b. Clean surface to be printed with aliphatic naphtha. Wipe dry with clean material and then allow surface to air dry for ten minutes.

c. Apply black ink (3.0h.(1)) to the prepared area using rubber stamp.

d. Air dry and overcoat with clear acrylic as specified in 5.4.3.3b.(6).

e. Overcoat clear acrylic with abrasion resistant varnish (3.0f.(2)).

5.5 INSTALLATION OF MARKERS

5.5.1 Attachment to Polyurethane Molded Parts

Bond patches to molded parts using procedure specified, except roughening of the molded part prior to cleaning is not required.

5.5.2 Heat-Shrinkable Tubing

Shrink in place in accordance with good standard practice.

5.5.3 Tied-On Sleeving

a. Tie all sleeves at both ends with braid (3.0c. or 3.0d.) using square knots unless the axial movement is restricted to one inch or less by obstructions such as bundle ties, clamps, or shielding.

b. On teflon insulated wire, two wraps of 1/2 inch tape (3.0t.) shall be applied, centered under the sleeve, before tying.

5.5.4 Adhesive Tape

a. After printing, wrap 2-1/2 $\pm$ 1/2 turns of the tape around the wire, wire harness, or cable jacket, so that at least one complete nomenclature appears on the outermost layer.

b. Where a complete nomenclature would not appear on the outermost wrap, apply tape around the circumference for one turn and pinch excess end lengths together to form flag. Fold flag back around and tie at both ends of tape with braid (3.0c.), using a square knot, as necessary to preclude flag damage during handling and installation.

c. P.I. marker tape flags, and flags inside equipment, are not required to be folded back and tied with braid unless the cables or wire bundles are to be pulled through conduit or other restricted openings which may result in damage to the flag.

5.5.4 (Continued)

d. When printed adhesive markers are to be installed over vinyl sleeving, do not use pressure sensitive tape directly applied. The use of adhesive tape is acceptable provided the adhesive does not come in contact with the vinyl sleeving. This may be accomplished by folding the tape back on itself and wrapping around the sleeving. If there is a possibility of the tape sliding on the cable, fasten securely by tying both ends of the tape with braid (3.0c.) using a square knot.

5.6 TEST METHODS

5.6.1 Permanent Marking Test

Marking shall be considered permanent if it is legible after being subjected to 20 strokes from a wire mark abrasion tester using a 1/16 inch gray felt abrasive in accordance with Federal Specification C-F-206, Type I, Class 9R4 Operate the tester either manually or under power on 3 or more imprints no sooner than 2 minutes after the coding operation if the mark is applied with a hot stamping machine, or no sooner than 4 hours after marking and curing if the mark is applied with a cold stamping machine (automatic typewriter).

6.0 QUALITY CONTROL

a. Quality Control shall perform surveillance of marked cables and harnesses to ensure conformance with the requirements of this specification. Particular attention should be paid to the following:

   (1) Correct markings placed on cables and harnesses.

   (2) Correct placement of markings on cables and harnesses.

   (3) Legibility of markings.

   (4) Use of proper type marking for cable jacket material and wires.

   (5) Verification of tests specified in 5.6.

b. Quality Control shall ensure that the operation of any device used for the marking processes mentioned in this specification conforms to the requirements.

APPENDIX C
FABRICATION & INSTALLATION PROCEDURES OF ALL E-3A
OPTICAL FIBER HARNESSES/LINKS

AIRPLANE ROUTING AREAS

The airplane routing areas where the harnesses are installed are shown in production illustration drawings 180-59000 and on. The environmental extremes in these areas are described in MIL-E-5400. Of special interest is the wheel well area. Cables installed in this area are subjected to the broadest range of temperatures and physical shocks on the airplane. In addition, accidental damage from repairs or changes to wheel tires or trucks, flaps, or conduit, from wind whipping, ice/water loading, rock or bird impact, or fluid contamination from hydraulic fluid, anti-icing compounds, jet fuel, or cleaning compounds is possible. Since truck fires must be positively contained within the wheel well area, installations must maintain present component integrity.

In order to meet the environmental requirements for this area, special installations are necessary. The present installation is made up of conduit-protected routing where the greatest danger of adverse exposure and the maximum flexure occurs; a special pressure bulkhead fitting is used to penetrate the bulkhead with integrity. Similar fixtures are necessary to install the fiber optics cables.

HARNESS DESCRIPTIONS

Each of the harnesses is clearly identified with a tape imprinted with the following information:

Harness identification is contained on blue tapes within 12 inches of each end of the bundle with the harness and dash numbers printed in characters 1/8 - 1/4 inch high.

First end - Where conduit or restricted area space does not permit a connector to be threaded through on the cable, the first end shall have the connector installed and installation shall commence from its mate-with location. The unterminated end shall be taped or otherwise protected so that the individual finished fiber optic surfaces are protected and the entire cable is taped to both protect and prevent separation of the individual fiber optics cables. If this is not accomplished in wire prep, the protection should be applied before leaving the shipping container.

PI flags - The bundles have green tags without markings. These correspond with location marker arrows shown in the PI drawings. When the bundle is properly installed, the green tags will be installed under the clamps.

Mate-with marker - Within 6 inches of each connector is a yellow identification tape which lists the connector equipment number and the equipment number of the receptacle with which the connector is mated.

IDENTIFICATION OF FIBER OPTICS CABLES AND HARNESSES

Identify all cable and cable harnesses per Appendix A as noted.

Unless otherwise noted all harness identifications shall be located per Figure C-1 and dimension tolerances shall be $\pm\frac{1}{4}$ inch. For overall shielded wire bundles with Expando sleeving.

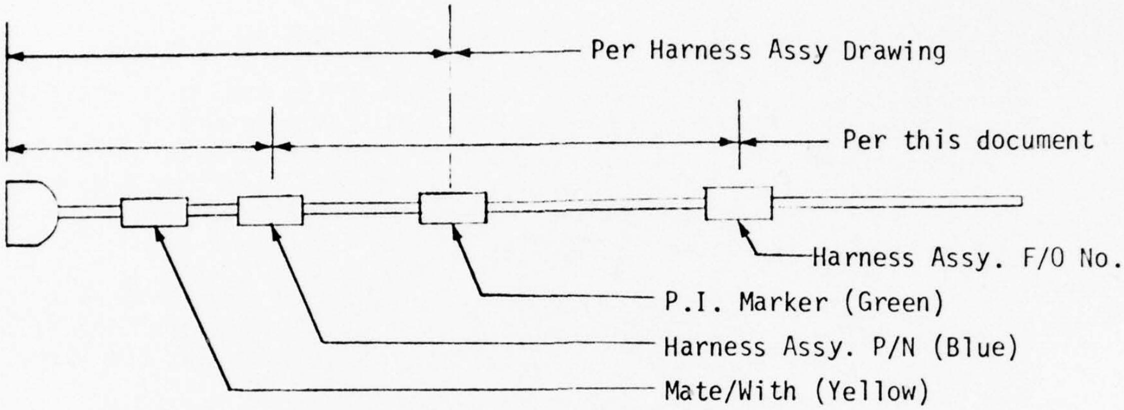


FIGURE C-1

Harness Part No., F/O No., and Short Title may all be on the same Identification Marker.

CABLE IDENTIFICATION

Use the following wire identification system: (see sample callout)

FØ0101-099-20R

- Harness Number — FØ0101
- Cable Number — 099
- Cable Size (if required) — 20
- Color Code (if required) — R

Harness Number

The harness number as it appears in the cable identification is the equipment number assigned to a specific harness by the cable harness Assembly Index Drawing

Cable Number

The cable number as it appears in the cable identification consists of sequencially assigned numbers. Jumpers and pigtails which are not assigned cable numbers by the Harness Assembly Drawing do not require identification.

Color Code

Color code as indicated on the Cable Harness Assembly.

SIZE	CODE IDENT. NO.	
A	81205	D180-24693-3
SCALE	REV	SHEET 4

INSTALLATION

SPECIAL HANDLING CAUTIONS

Glass has low impact and compressive strength. Never drop or hit the cable.

Glass has high tensile strength but low tolerance to elongation and shear. Microfractures otherwise unnoticeable may cause stress risers. Whipping, jerking, or flexing which exceed the installation limits, even momentarily, should be avoided.

The contact surfaces are precision finished and can be damaged by dust, oil from your fingers, or by scratching.

Leave the protective covers in place until closing the connector.

Check alignment of the connector shells when closing so that they're as straight as possible.

Shocks over 100 g's can occur inside a connector by seemingly minor roughness to the bundle near the connector. Be careful handling connectors.

SEQUENCE PLANNING

The sequence planning for the two harnesses is:

180-59001: Interrack Harness

Bundle tie table with excess length allowed at both ends.

Form board fabrication with excess length trimmed to with sufficient slack allowed for 3 subsequent reterminations at each end allowed. At this step, the ends must be capped off with tape or shrink sleeving and the end taped so no subsequent damage may occur.

Solder one (or laboratory functioning as solder one) where both ends have terminations, connector halves, and backshell hardware installed.

NOTE: Protective end caps are necessary for subsequent shipping.

NOTE: Check continuity and proper pins.

Final assembly for installation of cable but not end closure.

INSTALLATION STEPS

Harness 180-59001: Rack Integration Bundle

The 180-59001 harness will be installed in the same routing clamps as the 204-51870-5 harness which it replaces. The first end is installed at the floor joint shown in the production illustration.

(Continued)

Leave the connector protective cap in place until inspection is conducted. Measure, without connecting, the distance between the mate-with connector and the first run clamp and allow sufficient length so that, when the cable connector is mated, the cable directly behind the connector backshell is not stressed. The harness must not be installed with a 'flex point at the backshell; any flex distribution must run evenly from the backshell to the first cable clamp. See Figure C-2

FIBER OPTIC HARNESS CONFIGURATION

Harness configurations consist of fiber optic lines and pairs of standard wire that are twisted together. Various configurations are shown in Figures A-2 and A-3.

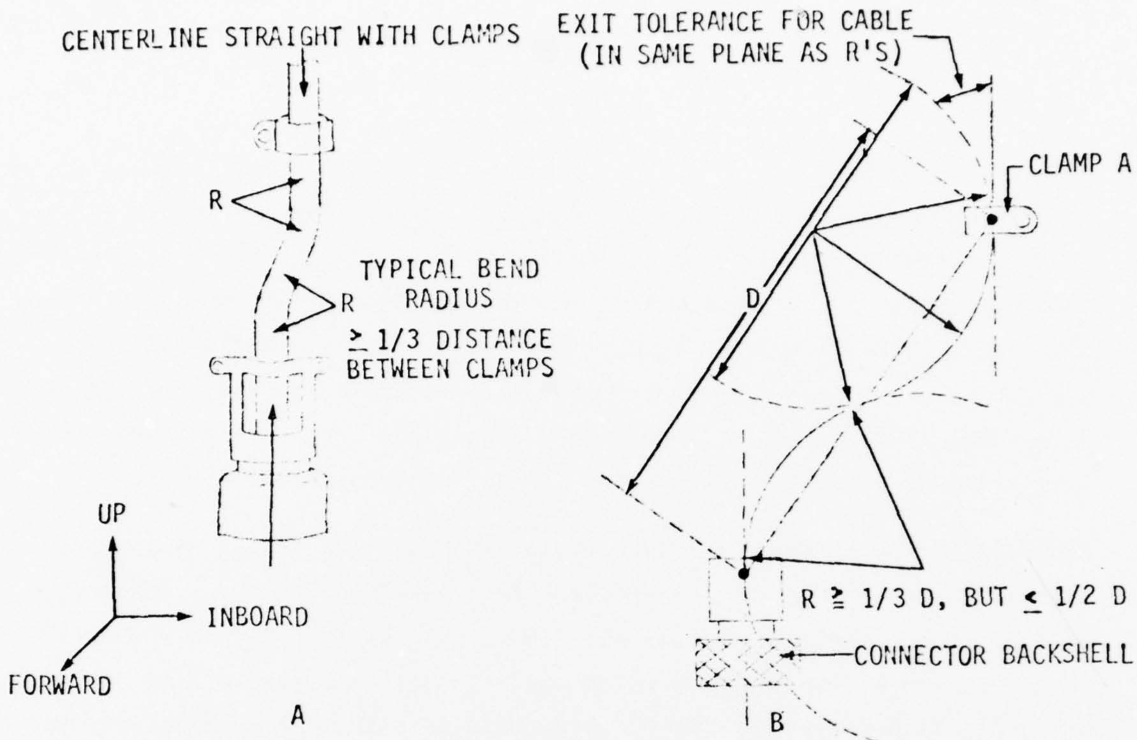


ILLUSTRATION 1: ACCEPTABLE INSTALLATION

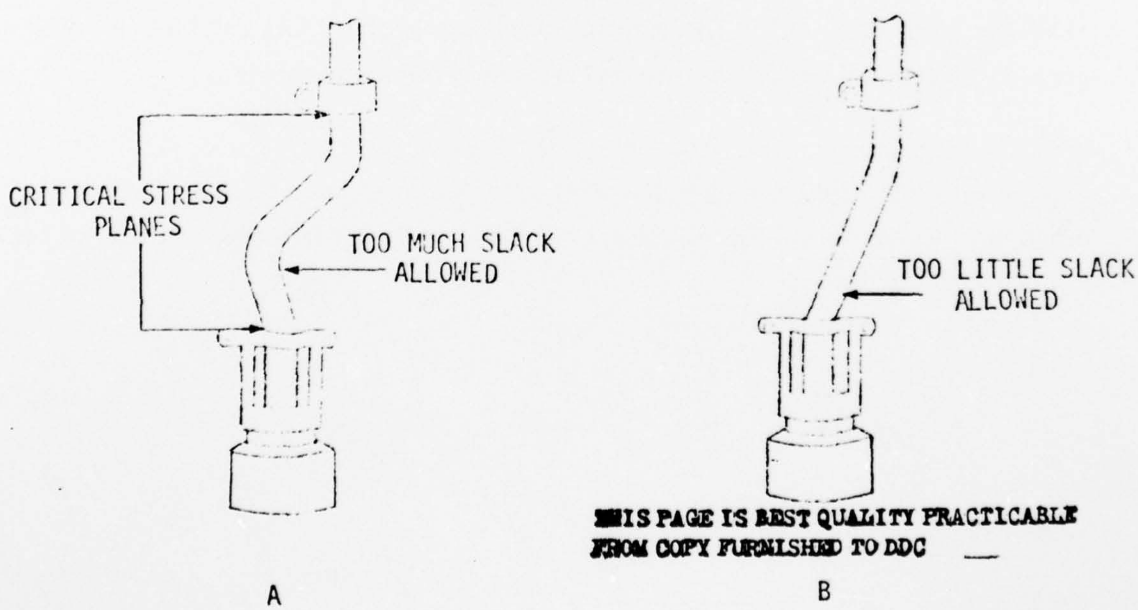


ILLUSTRATION 2: UNACCEPTABLE INSTALLATION

FIGURE C-2. EXAMPLE INSTALLATIONS

APPENDIX D
ROUTING TECHNIQUES

1.0 INTRODUCTION

The wiring in an aircraft is designed to withstand a broad range of adverse thermal, mechanical, and chemical environments. The performance levels of the installations have been determined by careful evaluation and trial and error to such an extent that electrical system reliability is taken for granted. Even though a modern commercial or military airplane has thousands of connectors with tens of thousands of individual contacts and the wiring total lengths are measured in miles, a malfunction circuit is rare.

Fiber optics is a new but similar field. Many of the lessons learned in standard electrical wiring can be used as a starting point for designing reliable fiber optic installations. It is the purpose of this document to summarize the design criteria which apply to both standard wiring and fiber optic cables and use this for a design base to establish a philosophy for fiber optics routing. To do this, the families of areas in the airplane where fiber optics could be routed will be grouped and critical design listings made for each. The routing philosophy presently applied to each area in designing electrical installations will be tabulated.

Finally, the comparative properties of fiber optic cables and electrical cables will be used to determine what changes need be made and hardware developed in order to determine where fiber optic technology can be successfully utilized.

2.0 SUMMARY AND CONCLUSIONS

An analysis was made of the routing techniques for fiber optic interconnects, comparing them with conventional electrical wire. Three main areas were addressed. These areas were:

1. Hazardous/sensitive area about the aircraft
2. The main aircraft locations and the expected environmental conditions
3. Fiber optic component capabilities to operate in either of the two above areas

In addition, standard routing procedures applicable to fiber optics were identified as part of the overall routing technique analysis.

The results of the analysis showed that fiber optics can now be safely routed through hazardous/environmentally stringent areas without sacrificing safety or performance. This is true because the glass-on-glass fiber bundle can withstand temperatures up to 600^{o}C prior to softening. The other well-established benefits such as no grounds and EMI immunity make the fiber itself attractive for most aircraft applications.

There are some routing precautions with the fiber, however. It has been reported that moisture has caused fiber cracking in stress areas such as in the bend radius. This will require special moisture protection or routing instructions that will clearly limit tensile or compression loads and excessive axial twisting, bending, and flexing.

One disadvantage to fiber optic interconnect systems is that signals cannot be reliably terminated or generated in hazardous/high temperature locations. This is due to the temperature sensitivity of the active components, particularly the laser diodes. During the analysis, it was found that the component manufacturers did not have the data that would allow a thorough analysis of the component characteristics as a function of several different environmental conditions. Although optical data was generally sufficient, full parametric characteristics were not identified. These characteristics include:

- Stability versus temperature
- Sensitivity versus temperature

- Activation energy
- Radiation effects
- Moisture/humidity resistance
- Stress (Mechanical)
- Electrical overstress effects on sources/detectors
- Thermal shock
- Contamination resistance

Although some research is being directed toward gathering data on the above areas, the data does not exist to firmly state that fiber optics can be used in all applications and locations. The trends for the active components, however, indicate that the active components may be used in hazardous/environmentally stringent areas in the mid-1980's.

Special routing techniques will also be necessary for termination and splicing aboard the aircraft. Splicing areas may have to be designated in order to allow for the necessary room and safety requirements necessary to make splices/terminations. This is an additional consideration that is not needed for conventional wire.

The area of splicing and termination as applied to field repair techniques is not well understood and will be addressed in subsequent phases of the program. Until the equipment is developed to allow effective splicing of fiber bundles, the routing techniques must allow for adequate room to repair or replace a broken fiber. An interim solution to this problem can be achieved by running unused bundles in the harness. Then, if one bundle breaks, a spare would be available and could be connected at the backshell of the connector. Although this approach is feasible, it begins to defeat some of the projected cost benefits of fiber optic interconnect systems.

The advantages to fiber optic interconnects have been explored and are well understood. These advantages, the main one being the absence of electrical current, will allow fiber optics to be applied in most areas of a military type aircraft. The currently identified disadvantages to routing fiber optics are:

- Moisture protection requirements
- Active component reliability
- Splicing/termination areas
- Limited data base for routing concepts

The methods developed for routing conventional wire into an aircraft are believed to be sufficient for fiber optics. Precautions to address the areas above must be considered in the fiber optic routing technique to allow for successful installations. It is believed that the identified technology problems can be resolved and that successful, reliable routing of fiber optics will occur for all areas of a military aircraft by mid-1980's.

3.0 ROUTING ANALYSIS

3.1 Basis for Routing

The installation of fiber optic cables in aircraft can be done using the techniques adapted from the installation and routing of standard electrical and coaxial cables. The experience obtained in experimental commercial-type installations and comparison of the properties of fiber optics cables with comparable electrical wire characteristics supports the feasibility of adapting standard routing techniques to installing fiber optics cables.

The performance standards of installed electrical cables are tested with well established procedures and limits. The limits of MIL-E-5400 and MIL-STD-810 define a standard of performance to check the equivalent fiber optics cables.

The installation procedures defined in Appendix B are based on standard practices of airplane installation. The installations produced have a satisfactory history of withstanding airplane service life. The installation and routing of fiber optics cables in the same manner, then, can be expected to provide an equally serviceable installation.

The successful installation and routing of fiber optics cables in two Boeing military-type aircraft (the ASW B-504 and the YC-14 aircrafts) has shown that prudent selection of the processes developed for conventional electrical cables can be successful with fiber optics. This philosophy will be carried forward in the analysis of routing techniques for fiber optics.

The primary areas to be analyzed in the routing of fiber optics are:

1) Where can fiber optics be routed in a military-type aircraft?
2) What are the environmental constraints of the aircraft areas?
3) How mature are the fiber optic components to withstand the required environmental conditions?

These areas will be discussed in the following sections.

3.2 Hazardous/Sensitive Routing Areas

The most obvious hazardous area that fiber optics can impact is the fuel tanks. It is imperative that no sparks be generated in this area in order to eliminate the advent of explosion. Similar "no spark" areas may exist in armament storage bays or areas of gaseous mixture with air. MIL-E-5400P considers explosion proofing as the inability of components to produce arcing or sparking.

With conventional electrical wiring, explosive areas are generally to be avoided because of the spark threat. However, when it is required to go through a fuel tank, for instance, the following routing additions are made:

- A metal conduit having a Teflon impregnated woven or wrapped glass fiber liner or a similar protective coating is used.
- All wiring within the conduit must be flame resistant per MIL-W-25038 or equivalent.
- Bond resistance for fire/explosion hazard area is applicable.
- All terminations in fire/explosion hazard areas should be potted or sealed using compatible material to prevent shorting or arcing.

This arrangement offers the greatest protection against fires or explosions resulting from shorted or overloaded wires, which otherwise would ground to the conduit wall and burn through.

Because fiber optics carries no electrical current, shorting or arcing is not a possibility. Therefore, the costly and complex steps listed above can be eliminated without sacrificing safety. This makes fiber optic fuel indicators and other control functions within fire/explosion hazard areas a reality.

High temperature areas also cause problems in routing interconnect systems. Typical hot areas include engines, engine nacelles, heaters, air conditioners, heat exchangers, and skin hot spot zones.

For conventional wiring, several precautions must be taken to prevent temperature damage. These rules include:

- Polyethylene dielectrics (used in coax) softens above 160°F. Bend radius must be 10D at any temperature.
- Bundle/route low temperature general purpose wire separates from high temperature wire and outside any area that may reach temperatures above 200°F.
- Provide clearance, thermal insulation, or baffles between wiring and heat generating parts such as electron tubes and power resistors to prevent deterioration.
- Route wires outside areas of thermal extremes.
- When routing wires or wire bundles in areas where there is heated equipment, thermal anti-icing ducts, or cabin air conditioning ducts, maintain the maximum spacing possible between the wire and the heater equipment.

Here, again, fiber optics technology eliminates extensive temperature damage protection schemes. Fiber interconnects, using a glass cladding over the silica (glass-on-glass) can withstand temperatures up to 600°C-800°C before softening occurs. Although the fibers can still be functional above this temperature range, it should be considered the upper limit of operation. Because of the high temperature capability, most of the precautions listed above are minimized in fiber optics. Common sense, however, must still prevail in that direct contact with a heating element such as a power resistor or heater heating element cannot be expected to extend the system's reliability. As a general rule, fiber optics cables should remain at least two inches away from heat generating sources.

Composite materials is a new technology that will be considered for future aircraft. The use of composites presents additional problems since the shielding effects of the aluminum structure will be lost. Shielding for conventional wire will be mandatory to reduce EMI/RFI susceptibility, guard against radiation (transmission) of data and protect against radiation damage. Figure D-1 indicates some of the applications that require shielding and would be particularly important in composite structures.

FIGURE D-1. CONVENTIONAL WIRE REQUIRING SHIELDNG/GROUNDING

APPLICATIONS

- All analog signal cables feeding wideband receiver circuits
  - A/D Converters
  - High Gain Amplifiers
- All digital signal cables feeding transient sensitive electronics
- All excitation power and measuring power cables
- All video lines
- All rf signal cables

EXAMPLE - SHIELDING REQUIREMENTS (EXTERNAL)

- Multiple grounded to chassis in most cases
- Audio/instrumentation circuits of 10MV or less (full scale) must be singly grounded
- Shields should not be contacted together at the chassis
- Touching shields should be avoided
- Use caution with shields for return circuits
- Shields must be grounded

The shielding requirements shown in Figure D-1 are just a partial listing of the rules that must be followed in protecting cables. The rules are extensive and add significantly to the cost of the system. Fiber optics would eliminate the need for this extensive grounding due to the fact that it does not carry current. In fact, for the fiber optic harness selected for this program, the conventional harness which contains 114 terminations of wires, jumpers, shields, and ground was reduced to 56 terminations wires, shields and grounds in the new fiber optic/conventional hybrid design. This reduction was due to the elimination of jumpers, shields, and grounds on the small signal lines which were replaced with fiber optics (the power lines remained in the new harness along with the associated grounds and shields).

Fiber optics, therefore, can be routed in composite structures without sacrificing cost, weight, and security. This is true not only in composites, but in other applications requiring extensive shielding or security. Security is one area where fiber optics can be very beneficial. Because it does not radiate energy or is difficult to tap into (particularly on an aircraft), the use of encryption techniques would not be necessary for on-board data processing and transfer of secure information.

In areas where interference coupling control is mandatory to minimize EMI, special precautions must be taken with conventional interconnect systems. Because EMI can be induced on the wires, circuit design criteria must be implemented. These factors include:

- Balance of Circuitry
    - minimize capacitive coupling
    - wires covered with high dielectric insulation
    - special isolation
    - properly twisted wires
- Impedance of Circuit
    - design for lowest practical impedance
- Bandwidth of Circuit
    - noise increases with bandwidth

Twisting the wires is a common practice in reducing mutual inductance (for a balanced circuit). Specific instructions are set forth to define and control the twisting.

Fiber optics on the other hand cannot be affected by EMI. Therefore, circuit design is simplified as well as the installation and routing procedures. No special precautions are known that will be necessary to route fiber optics in high EMI areas.

Protection from contamination should be the same for fiber optics technology as for conventional wire. Some of the routing considerations are:

- Do not route wires under or near tubing connections.
- Route wiring at least three inches away from hydraulic lines.
- Locate wiring at least six inches from fuel and oxygen lines. If this spacing is impossible, a minimum separation of two inches is allowable provided both the wiring and lines are separately secured and clamped.
- Route wiring so that electric terminations will not occur adjacent to lines carrying oxygen or flammable substances (to prevent arcing due to use of service tools).
- Do not route wiring near batteries or under fluid lines (especially connections), sumps, or pumps. If such routing cannot be avoided, adequate protection must be provided against contamination.
- Fiber optic interconnects should avoid high moisture areas to reduce the effects of microcracking.

Sensitive circuits are those circuits which are susceptible to noise, crosstalk, or other anomalies that can adversely affect performance. These circuits include:

- Sensitive circuits over 5 volts or over 1/2 ampere.
- Ac and switched dc power and control circuits.
- RF power circuits.
- Video and digital power circuits.
- Dc and low-frequency signal circuits.

- Video and digital-logic signal circuits.
- RF signal circuits.

These circuits require special routing considerations to nullify induced noise. Although fiber optics cannot replace all of the above functions, they can replace video and digital lines, which would reduce design costs and the associated cost of special routing techniques.

A summary of the hazardous/sensitive areas that can benefit from the routing of fiber optic interconnect is given in Table D-1.

3.3 Routing in Various Aircraft Environments

The environments in which fiber optic interconnects are defined in MIL-E-5400P. The major environments are listed in Table D-2 along with the limits in which the equipment must operate. The worst case environments were chosen as a goal for the utilization of fiber optics.

There are six major areas of an airplane in which routing of fiber optics will take place. These areas are:

- Nose gear
Wheel gear
Radome } Special wiring and moisture resistance (SWAMP)
- Vertical stabilizer
- Wings and tail section (Leading/trailing edges)
- Pressurized areas
- Fuel areas (wings) and other hazardous areas
- Engine and engine nacelle

These areas all have their own unique environmental conditions, all within the limits specified in MIL-E-5400P. Many of the applications mentioned in the previous section will be routed through these areas and it must be known whether or not fiber optics can survive.

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AIRBORNE FIBER OPTICS MANUFACTURING TECHNOLOGY. AIRCRAFT INSTAL--ETC(U)
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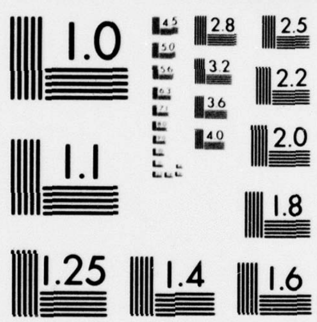

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

TABLE D-1. COMPARISON OF ROUTING CONVENTIONAL WIRE AND FIBER OPTICS FOR SEVERAL HAZARDOUS/SENSITIVE AREAS

HAZARDOUS/SENSITIVE AREA	CONVENTIONAL WIRE	FIBER OPTICS
Fuel and Other Explosion Areas	Metal Conduit with Teflon Impregnated Glass Fiber Liner	No Special Routing Provisions
High Temperature	· Route Wires Outside of Thermal Extremes · Maximize Spacing from Heat Generating Parts	· Fibers Can Be Routed into High Temp. Areas with Proper Cladding · Sources/Detectors Suspect
Outer Skin of Composite Materials	· Protection Against EMI Susceptibility · Guard Against Radiation Transmission · Protection Against Radiation Damage	No Special Precautions Except Under Radiation Environment
High Energy Emission	· Balanced Circuits · Minimize Coupling · Bandwidth Limited	No Special Provisions
High Contamination	· Do Not Route Near Tubing Connectors · 3" from Hydraulic Lines · 6" from Fuel/Oxygen Lines	Same Basic Provisions as Conventional Wire
Sensitive Circuits	· Must be Routed Separately · Shielding/Grounding	· Can be Routed in Same Bundle · No Shielding Necessary

TABLE D-2. MAJOR ENVIRONMENTAL REQUIREMENTS PER MIL-E-5400P

ENVIRONMENT	REQUIREMENT
Altitude	100,000 Ft.
Temperature	$-54^{o}C$ to $+125^{o}C$ (+150 Intermittent)
Corona	MIL-STD-454, Requirement 45
Temperature - Humidity	Figure 3, MIL-E-5400P
Vibration	Figure 2, MIL-E-5400P (105 at 2KHz, Max.)
Shock	18 Impact Shocks of 15 g.
Sand and Dust	"As In Operational World"
Fungus	No Fungus Growth in Tropical Environments
Salt - Atmosphere	Exposure to Salt-Sea Atmosphere
Explosive Conditions	No Ignition

A matrix of aircraft areas (including composite material structures) as a function of environment is shown in Table D-3. A comparison of each environment was made as a function aircraft location, comparing fiber optics to conventional wiring. In the matrix, a benefit showed up as a (+), a drawback or item requiring special routing considerations, was indicated by a (-) and a blank meant that there was no advantage of one technology over another. In most cases, fiber optics is shown to behave better than conventional wiring mainly because of the absence of electrical current and the fact that the glass has a high transition temperature. The main drawback is that moisture can induce cracking in fibers when the fiber is in a stressed condition (such as at a bend radius).

Because the environmental conditions in which the interconnects must operate are known and controlled by specifications, the major question to be resolved is - can the individual components survive in the various aircraft locations and environments? This subject is addressed in the next section.

3.4 Component Selection

While the basic advantages to fiber optics as a technology are well known, the detailed parameters of the components making up the fiber optics systems are generally either obscured in various vendor specifications or left out completely.

The light output (optical power) of optical sources is a major parameter to consider in any system design. This parameter is quite sensitive to temperature and aging effects and this sensitivity varies from type to type and from manufacturer to manufacturer. The lower power edge emitters and cell type devices have a higher reliability record and are considerably less sensitive to temperature.

Injection lasers on the other hand are quite temperature sensitive, have a narrow temperature operating band, and are still subject to sudden catastrophic failure in seemingly well designed systems.

TABLE D-3. ENVIRONMENTAL REQUIREMENTS VERSUS AIRCRAFT LOCATION

Location	Requirement	Altitude	High Temp.	Low Temp.	Temp. Shock	Temp.-Altitude	Moisture Resist.	Humidity	Salt Atmos.	Sand & Dust	Explosive Atmos.	Acceleration	Vibration	Electrical Noise	Mech. Shock	Temp./Humid/Altitude	Metallic Shielding	Corona	EMI	Anti-Jamming	Corrosion Resist.	
Nose Gear Wheel Gear Radome	C		-	-			+	+	+		-			-			-	-	-	-		
	F/O		+	+			-	-	-		+			+			+	+	+	+		
Vertical Stabilizer	C		-	-							-			-			-	-	-	-		
	F/O		+	+							+			+			+	+	+	+		
Wings and Tail Section (Leading/ Trailing Edges)	C		-	-							-			-			-	-	-	-		
	F/O		+	+							+			+			+	+	+	+		
Pressurized Areas	C		-	-							-			-			-	-	-	-		
	F/O		+	+							+			+			+	+	+	+		
Fuel and Other Hazardous Areas	C		-	-							-			-			-	-	-	-		
	F/O		+	+							+			+			+	+	+	+		
Engine and Engine Nacelle	C		-	-			+	+	+		-			-			-	-	-	-		
	F/O		+	+			-	-	-		+			+			+	+	+	+		
Composite Material Areas	C		-	-							-			-			-	-	-	-		
	F/O		+	+							+			+			+	+	+	+		

Detectors used are of two general types: PIN and APD. The PIN type is quite stable even being used as a reference standard for optical power measurement, while the APD, which may have from 100 to 600 times the PIN diode detection sensitivity (gain), is plagued with extreme gain vs. temperature sensitivity and a high noise figure at high gain settings. Reliability of both devices is good.

Fiber optic connectors are being rapidly developed by many of the old line connector companies as well as a few new ones. While parametric data on the materials used in these connectors is available, the variation in optical parameters to be expected during mechanical and environmental stress has not yet been documented so that operating life and performance degradation data are virtually unknown. While fiber bundle connectors appear to be more forgiving in terms of alignment tolerance, other characteristics such as high insertion and connector loss may relegate bundle technology to that of a 1st generation technology only.

Fiber optics cable optical parameters are based primarily upon the materials used for core and cladding (in the case of step index fibers), but changes in these parameters due to mechanical and environmental stresses are for the most part not too well known although studies are in progress, particularly with respect to radiation effects. Cold weather operation of some plastic clad silica fibers seems to be marginal, reportedly due to microbends caused by TC differences in the core and cladding. Effects of shock and vibration are particularly lacking and must be characterized before the full potential of fiber optics can be exploited.

Table D-4 lists the main advantages and disadvantages of fiber optic components plus an outlook for resolving the major problems. It is shown that the limiting factors are not the cables but the electro-optic devices, which are now very temperature sensitive. Improvements are expected to be made in all areas so that fiber optics can be successfully utilized in most military aircraft applications by the mid-1980's.

TABLE D-4. FIBER OPTIC COMPONENT OUTLOOK

COMPONENT	TYPE	ADVANTAGES	DISADVANTAGES	FUTURE OUTLOOK (1980-1985)
Source	Injection Lasers	Gallium Arsenide devices High power 1-10 MW	Stability (Operating Point) vs. Temperature Life vs. Temperature Coupling Loss to Cable	Both life & stability is improving
	Edge or Well Emmitters	Stability Life	Low Power 10μW - 1MW	Higher power devices becoming available
Detector	PIN	Silicon devices Stable Low Noise	Lower Sensitivity	Gradual improvement
	APD	Sensitivity	Operating Point Instability	Gradual improvement
Connector	Bundle	Available to a Mil Spec in single termination form	Termination time high Losses 3-5dB	Multi-terminal connectors becoming available
	Single Fiber	Low loss	Cost, Availability, Alignment critical	Multi-terminal connectors becoming available
	Conventional Wire	Available at low cost		Mature technology
Cable	Bundle	Redundant paths Multiple sources Low insertion loss	Higher cost Higher loss Cannot be spliced	Will be a limited usage item
	Single Fiber	Low cost Low loss	High insertion loss Termination difficult	Usage going up Prices going down
	Wire	Can be spliced and coupled	EMI Higher cost Higher weight	Mature technology

3.5 General Routing Considerations

The major portion of this report has dealt with the subject of what applications and in which locations can fiber optics be successfully used. There are other considerations, however, to the successful implementation of fiber optics in an airframe. These considerations are discussed in this section.

3.5.1 Handling During Routing

During the installation process, the cable must be routed through conduit, bulkhead fittings, and around bulkhead grommets without damage. Damage could occur due to tensile breakage, impact, bend stress, or scraping, or by contaminating the prepared contact surfaces.

The protection of the contact surfaces from contamination or scratches requires capping of the connector if installed. Where the cable without connector must be pulled through conduit or bulkheads, the contact ends must be protected by covering each prepared surface with a lintfree cloth patch and tape or shrink sleevings covering the entire cable end for stability. The cable pull cord is the fastener as with a standard cable since the mechanical strength of the cable is as great as standard cabling.

Impact is more critical and, since it's unintentional, can be installed without detection. Only attention can prevent this type of damage completely. The construction of the cable types being used with strength members provides protection from many minor impacts. Installation within cables of standard electrical wiring further reduces the chance of such damage. Caution during installation and a post installation continuity check are sufficient checks to assure adequate installation.

Bend stresses in fiber optic cables can withstand the same bends that electrical cables can. It is only at the ends where stress is concentrated. This is due to connector termination or the pull through process. The protection provided by the surface protection, or by the connector and backshell hardware, is sufficient to prevent such inadvertent damage.

Scraping is seldom a problem, and since the jacket of fiber optics cable does not serve as a dielectric, only the integrity of the strength members under the jacket and the optic member need be of concern. Examination of the cable and continuity of the conductor is necessary to determine that no damage has occurred.

3.5.2 Installation Hardware

The standard electrical hardware is designed to prevent dielectric damage to electrical wiring. Hardware is available for each of the airplane areas. If the material strengths of the fiber optics cables are equivalent to the electric cables insulation, then equal performance will be obtained.

Additional installation and field repair hardware will be identified in subsequent phases of this program.

3.5.3 Physical Damage Prevention

Like conventional wire, fiber optics must use standard practice to prevent physical damage in the routing. These general practices will include:

- Route wiring to avoid damage from being stepped on, being used as handholds or support for equipment, and being damaged from cargo stowage and shifting.
- Where wiring passes through cutouts or holes in structure, specify that .25 inch minimum clearance be maintained. For applications using a clamp, grommet, or adapter close to the cutout, .125 inch clearance is recommended, with the design minimum .06 inch. Allowance should be made for clamp tolerances, possible movement due to acceleration or vibration, and for rough handling during installation and maintenance.
- Provide sufficient clearance to prevent the chafing of wiring against any object in the maximum envelope of movement due to gravity, acceleration, or vibration.
- Route wiring at least three inches away from control cables if possible. If this cannot be done, specify the minimum allowable spacing on the engineering drawing; specify rigid support of wiring and, if necessary, provide special mechanical or electrical protection between wiring and control cables.

3.5.4 Flight Vehicle Routing

As with conventional wiring, fiber optic systems incorporating redundant systems must be separated to minimize the effects of fire, explosion, or other damage which may take a system out of service. Other critical systems which should have separate bundle routing include:

- Electrical "Fly-By-Wire" flight control systems
- Automatic flight controls
- Stability augmentation
- Stabilizer trim control
- Electroexplosive devices
- Engine controls
- Fire detection
- Fire extinguishing
- Fuel firewall valves
- Hydraulic fluid cutoff valves

Special routing considerations for flight vehicle equipment include:

- Route wiring to the pilot's and copilot's flight instruments separately.
- Do not route interphone wiring in a bundle containing wires from other systems except in the control columns. Service interphone wiring may be routed with passenger address wiring. In wings and nacelles this wiring may be routed with low power dc circuits.
- Route wiring to the control panels on the pilot's control stand to permit rearrangement of the panels without rewiring.
- Separate the generator control wires into individual bundles for each generator.
- Do not route wiring in emergency exit cut in or cut out areas.
- Route wiring in wheel wells and on landing gear to prevent damage from rocks, ice, and mud.

3.5.5 Repairability

Rework of an electrical cable can result from system redesign, replacement of components, damage, or random failures of parts. Provision is made for rework in both the component design and the cable installation for standard electrical cables. Contacts are removable from the connector to minimize replacement cost. The contacts are fastened to the wire by solder or by crimping. All of the steps can be accomplished with simple, handheld tools.

To perform the same functions on fiber optics cables, a more complicated process must be followed. In most cases, an epoxy glue is used to fasten the contact to the fiber optic conductor. The strength member must be fastened to the connector as an extra step which is not required for standard wiring. Some of the fiber optic connectors do not even have removable center contacts, requiring a "cut and throw" process to replace the contact. The contact face then must be polished or a clean face produced by fracturing, both procedures requiring a special tool.

To be economical from a production and in-service rework viewpoint, the epoxy step must be eliminated or speeded up, as well as the fracture or polish step. The strength member fastening could be made as rapid as fastening a shield to a standard connector, but, at least, the tool is handheld, and so might be permissible.

Because this termination activity is more complex than standard wire, special provisions must be made in the routing to allow adequate room and safety to perform this function. Similar consideration should also be given to the splicing of the fibers. Dedicated splicing areas should be defined in the initial routing analysis in order to minimize the impact of fiber breakage on the overall system availability.

APPENDIX E
MANUFACTURING PROCESS FOR FIBER OPTIC INTERCONNECT SYSTEM, PRELIMINARY COST ANALYSIS REPORT

INTRODUCTION

The objective of this cost analysis effort is to be able to identify the associated fiber optic manufacturing costs and then to determine the cost of inspecting and installing fiber optic harnesses aboard military aircraft. High cost and beneficial cost areas will be identified, and recommended improvements in the manufacturing process will be given. A "cost of installation" comparison will be made between standard electrical wire installation practices and those necessary for fiber optics.

COST SUMMARY

An important assumption has been made that must be recognized as a basis for the results of this life-cycle cost analysis. Material costs are based on current vendor estimates but production set-up cost and other engineering/manufacturing costs are based on a futuristic analysis and prediction of a large production of fiber optic harnesses fabricated at a rate typical of wire harnesses.

The overall results from Boeing's parametric cost model (PCM) indicate a per system cost for this project's twenty-one systems at $7893 for technology developments. Projecting these initial costs and manufacturing technology concepts to a planning production cost base, the fiber optic harness cost will be about $3620, which is a reduction of more than half of the initial technology development costs. Wire harness costs per system are about $4900, which is a nine-percent increase over the optical fiber harness. Engineering costs are reduced by 38 percent for the fiber optic harness and manufacturing costs are reduced by 16 percent. Because of the high cost of the connectors, fiber optic material costs have increased above wire material costs by nearly 300 percent. With a reduction in connector costs, fiber optic harness production costs will be greatly reduced.

COST FACTORS

The cost information provided is based on a full scale production run as well as actual incurred costs for a production of 20 harnesses. The cost factors addressed include:

a) Material - cost data was collected, segregated, and analyzed for the various types and quantities of materials available for the harness fabrication. Unusual delivery schedules were taken into account as a factor in maintaining an orderly production yield. Similarly, electrical component material costs were also collected for comparison purposes.

b) Production Set-up - the cost to provide assembly line production operations for fabrication was determined. This included the required production facilities space, tooling, and set-up labor hours.

c) Special Handling and Processing - automated, manual and special handling techniques were evaluated for cost impact. Polishing and grinding tools unique only to fiber optic bundle cable differ significantly from conventional wire terminations. Automated versus manual terminating techniques and harnessing techniques were considered in this evaluation.

d) Assembly Installation Time - harness installation man-hours and procedures established for electrical harnessing have been compared to estimated man-hours for fiber optic harness installation. Actual labor hours will be collected and evaluated during the future phases of this project.

e) Quality Control - quality control labor hours and equipment costs were identified to test and evaluate the harnesses.

f) Manufacturing - the manufacturing process flow for several wire processes and a fiber optic process were identifed along with the estimated labor hours.

g) Test Equipment - Costs were identified for current and proposed required test equipment.

h) Other Additional Factors - other pertinent factors which affect fiber optic harness costs and benefits include: operations, reliability and maintainability predictions; spares, repair parts, and inventory estimates; training costs and options; weight and size for shipping and storage; manufacturing, installation and operation safety; and special routing advantages and handling fatigue factors.

Cost Analysis Description

This cost analysis includes acquistion cost elements involved in producing fiber optic harnesses in a modern production and manufacturing facility. It also includes ownership cost elements derived from applicable historical data and from reliability and maintainability analysis.

Production set-up costs, the non-recurring costs, are based on the assumption of a production facility which is of minimal scale for yielding economy from advanced automated equipment and methods. Equipment costs are based on quotes or estimates of purchase prices or upon engineering estimates.

Manufacturing costs, the recurring costs, relate primarily to the flow of tasks and processes which generally dictate the big share of the cost of a harness assembly.

Production and manufacturing cost estimates are based on a survey and analysis of company experience in producing large and small quantities of wire harness assemblies for both military and commercial programs. Three separate and distinctly different company production/manufacturing facilities provide the primary base of experience. The approach is to correlate this experience with similar tasks related to production/manufacturing of a fiber optics harness assembly and then to provide engineering estimates of unique equipment, tasks or processes. These results are supported by harness assembly cost model estimates and by gross level cost factors established from direct experience on past and ongoing company programs.

Operation and support costs analyses are based on historical data on the E-3A aircraft along with an extensive history on four Navy aircraft, the S-3A, E-2C, P-3C and EC130G and Q.

A reliability analysis of both the baseline wire harness assembly and the fiber optics assembly provides the added information base appropriate for prediction of fiber optic harness field reliability maintenance factors. Policies of the using agency relative to inventory, spares, and repair parts appears to be the dominant factor affecting the supply and support cost factors. Since the baseline harness assembly is for an E-3A aircraft, the policy for this aircraft was selected as a baseline in conjunction with policies formulated in the A-7 ALOFT Project Technical Report NELC TR2024, 1998, 1982 and 1968. Some cost elements are also derived based on operational efficiencies that could be realized for a fiber optic harness configured E-3A.

MANUFACTURING DESIGN, DEVELOPMENT, TEST & EVALUATION COSTS

The Boeing acquisition cost model, PCM, was exercised using finely tuned inputs established from data and experience compiled on the baseline wire harness assembly. The baseline wire harness assembly cost was established by engineering and finance records which correlated very closely and was verified by the Design-to-Life-Cycle Cost (DTLCC) cable assembly model.

The baseline cable assembly was assumed to have been produced as part of a matured large-quantity production process. Since the fiber optic assembly PCM model run is referenced to the matured wire harness baseline, application of improvement curves to the fiber optics process should provide reasonable prediction of matured production costs. In view of harness and cable assembly experience of the past and in view of the strong improvement potential offered by fiber optics, PCM mode runs were made using improvement curve slopes of 85 and 90 percent. These technology developments costs are broken down into more detail in table E-1.

Table E-1

Fiber Optic Interconnect System Cost Estimates

Cost Element	Cost Goal
Direct Labor	
Engineering	$ 1,465
Developmental Elec. Mil.	508
Quality Assurance	34
Program Finance Controls	210
Total Direct Labor	$ 2,217
Labor Overhead	
Engineering	453
Manufacturing Elec. Mil.	441
Quality Assurance	25
Program Contracts	567
Total Labor Overhead	$ 1,486
Travel	36
Other Direct Costs	
Fringe Benefits	995
Freight-In	28
Product Liability Insurance	2
Sub Total (All of above)	$ 4,728
General and Admin. Expense	
Products New Business	811
Puget Sound	136
Total G&A	$ 947
Direct Materials	
Production Materials	$ 1,217
Washington State Taxes	$ 89
BCS	$ 6
Total Estimated Cost	$ 6,987
Profit	849
Total Price	7,836
CAS 414 Cost	57
Total Grand Price	$ 7,893

Note: The above estimates were derived from proposal estimates by extracting the stand-alone link engineering costs and then by factoring other costs by 22 (the total number of harnesses to be produced under the current contract).

PRODUCTION SET-UP COSTS

The most logical and practical approach for fiber optic harness production set-up would, of course, be that of expanding capabilities of an existing wire harness production facility. This approach may, however, lead to expansion of physical facilities through expansion into adjacent facilities, building onto existing facilities, completely relocating facilities, building and locating within new facilities, etc. The situation may also exist where the production demands on existing facilities would warrant establishment of a completely new and distinctly separate facility within existing facilities, leased facilities, new facilities, etc.

EQUIPMENT REQUIREMENTS

The Ink Jet Marking System offers critical benefits. Application of this system would be basic if marking of individual fiber cables and wires is required and if any significant level of production is anticipated.

For quantities which approach medium production rate levels the Ewbanks automatic stripping machine would be recommended for achieving labor efficiency. The suitability of this machine for cutting the Kevlar strength member and associated jacket material of the fiber cables would require evaluation and probable modification. Assessment, adjustment and modification would be required to assure that the fiber elements are not damaged.

The outstanding dominant fabrication cost element is the epoxy, dry, cure, grind, and polish process. Some concept and development work has been done towards an automated machine to effectively and efficiently accomplish these tasks. The potential for high yields and efficiencies of fiber optic harness production hinges largely on this type of a development. A semi-automatic approach patterned after existing laboratory techniques is an alternate lower initial investment cost option. This option would be a likely candidate in production support of a variety of production quantities in the low to medium production rate categories. A third option would obviously be that of a laboratory set-up such as presently exists in the fiber optics laboratories.

In addition to the basic fixed position grind and polish equipment referenced above, equipment and tools which are portable or can be easily manipulated are required for epoxy, dry, cure, grind and polish operations after the harness or cable has been formed.

In summary, production equipment and tool developments are needed to achieve potentials offered by fiber optics. At least four basic options are apparent at this point and a decision relative to the options to pursue could have significant life-cycle-cost impact.

Facility Requirements

Basic facilities accommodations will consist of normal lighting, ventilation and heating with either normal height or raised ceilings. Air conditioning would be required in the epoxy, dry and cure areas along with possible exhaust ducts. Approximately six high voltage outlets need to be provided. Some rough order-of-magnitude cost-estimating relationships for facilities of the nature required are given below:

(1) Refurbished Facility

Without air conditioning - $45.00 per sq. ft.

With air conditioning - $60.00 per sq. ft.

These refurbishments to include heat/ventilation/lighting, standard electrical outlets and air drops.

(2) New Facility

Without air conditioning - $90.00 per sq. ft.

With air conditioning - $100.00 per sq. ft.

A new facility would most likely require additional square footage for support areas.

(3) Special Utilities

a. Large equipment/machine electrical connection - $1500

b. Air hook-ups $ 300

c. Water hook-ups $ 300

Training Requirements

Two training courses are required. One course would be a 16 hour familiarization level course which would present concepts and relationships governing the application of fiber optics technology. This course would also emphasize critical care, handling, test and trouble shooting aspects of real hardware and would exercise student knowledge through mental and paper exercises as well as through elementary tasks involving real hardware as training devices. Some laboratory, manufacturing and test equipment would also be demonstrated with student participation.

This course would be designed for supervisors, engineers, quality inspectors, and others whose basic understanding is important to the evaluation and decision making processes related to successful development and application of fiber optics technology. A second course would be a certification course designed for manufacturing personnel and for developmental, test, and installation and handling technicians. A 24 hour session is recommended which would have the same general content as the 16 hour course except with less emphasis and a more simplified approach relative to concepts and relationships governing the applications of fiber optics technology. This course would also have greater emphasis applied to the critical care, handling, test and trouble-shooting aspects and would make extensive use of hardware training devices for developing and verifying student understanding and physical skills.

Manufacturing Costs

The manufacturing process flow manhours is the dominant factor related to manufacturing costs. The tasks and steps and related timelines for the baseline wire harness assembly have been estimated by Finance and by mechanical and industrial engineering specialists. Similar estimates have then been applied to a planned fiber optics harness assembly process with the addition of unique steps and processes. It will be observed that the epoxy/dry/cure/grind/polish task is the dominant cost factor. Efficiencies therefore hinge to a large degree upon development of automated equipment and expedient techniques. A list of steps and assoicated labor hours is presented in Table E-2.

Some estimates of fabrication costs of the fiber optic harnesses utilized in the YC-14 were made based on the assumption of a cost break-down similar to this contract. That is, assume that the company which fabricated the eight YC-14 fiber optic harnesses/cables did so as part of a DDT&E effort which allocated 12 percent of the total cable cost to fabrication. In this case $167 of the $1393.00 purchase price would be allocated to fabrication. Further, assuming that technology advancements and labor rates act to balance cost effects of fabrication, then this would equate to approximately 5 manhours at a $34 per manhour manufacturing.

The DTLCC cable assembly computer model estimated an average cost of approximately 8 manhours for each of eight equivalent wire harnesses produced on an improvement curve with a 90% slope.

The above results suggest that fiber optics manufacturing and fabrication experience of the past offers economies at least comparable to wire harness assemblies. It should be observed that three assemblies were utilized on two YC-14 aircraft (six harnesses) with no failures in over 600 flight hours. Each of the harnesses included four fiber cables and two connectors.

Fiber Optic Harness Assembly

			Cost Estimate Manhours Goal
1.	Cut and Code		1.0
2.	Fiber Ends - Epoxy, Dry/Cure, Grind and Polish	20X.33	6.6
3.	Wire Ends - Strip and Crimp	12X.06	.7
4.	First End Connector - (less than wire) install pints		.7
5.	Form Board Layout and Tie		2.2
6.	Jacket - Braid or Install		2.5
7.	Fiber Ends - Cut, Epoxy, Dry/Cure, Grind and Polish	20X.33	6.6
8.	Wire Ends - Strip and Crimp	12X.06	.7
9.	Second End Connector - Install Pins		.9
10.	Labels/Patches/Tape		.8
11.	Test		.3
12.	Pack and Ship		.3
		TOTALS	23.3

TABLE E-2

Production Materials Costs

The materials costs for the fiber optics harness assembly and the wire harness assembly are presented in tables E-3 and E-4, respectively. These estimates of single harness costs were established from vendor quotes.

TABLE E-3

Fiber Optics Harness Assembly Materials Cost Estimate

Material Description	Quantity	Cost
1 - Connector MS3476 L24-19P	3	$1100
2 - Connector MS3476 L14-4P	3	
3 - Single fiber cable @ $1.50/M	10M	15
4 - Fiber bundle cable - 46 mil @ $1.75/M	160M	280
5 - Wire - Twists pair M27500-22-MY-2400 @ $0.14/ft.	120 ft.	17
6 - Epoxy		5
7 - Braided Jacket/Patches/Tape, etc.	-	-
		$1417

TABLE E-4

Wire Harness Assemblies Materials Cost Estimate

Material Description	Quantity	Cost
1 - Connector 27467T23B53P with adapter	1	41
2 - Connector 27467T15B35SA with adapter	2	44
3 - Connector 27467T11B35S	4	109
4 - Wire, single conductor @ $0.065/ft.	58 ft.	300
5 - Wire, twisted pair M27500-22-MY-2400 @ 0.14/ft.	219 ft.	
6 - Wire, twisted pair shielded @ 0.46/ft.	204 ft.	
7 - Braided wire shield		
8 - Braided nylon jacket		
9 - Patches/sleeving/tape		
		$494

Installation Cost Estimates

Estimate for the installation of a group of harness assemblies which include the baseline wire harness assembly during aircraft production is approximately six hours. Since, during cable installation a group of cables are installed at one time, the exact time lines for a single cable are not traced. However, installation of the baseline harness by itself would approach four to six hours and would tend toward four hours. The estimation of removal and replacement of the baseline assembly is twenty-six hours. Installation and removal and replacement estimates are roughly proportional to the size and weight of the harness assembly. Hence, if the fiber optics harness is 50% smaller and lighter then a potential savings of 50% would be realizable.

Operations and Support Costs

A historical data base for estimating installation, operation, and support costs for fiber optics harnesses has been found to be extremely limited as is data for MTBF and MTTR estimates. The experience record of six fiber optic harnesses (four fiber bundles per harness) utilized in the YC-14 aircraft avionics system reflects zero failures in over 600 flight hours. A historical base for wire harnesses in military and commercial aircraft is also relatively limited. Wire harness failures and maintenance actions are mostly recorded in a category too general for comparison purposes or else they are included in a category associated with the system or subsystem of which they are a part. A search of service history records on military aircraft uncovered some data on five aircraft. The lack of data suggested above is judged to be a proper policy to be exercised by the services in the interest of minimizing life-cycle-costs. This conclusions is based on a judgement of costs attributed to failure and maintenance of harnesses and cables as compared to costs of maintaining detailed records.

Operational Benefits

The E-3A aircraft which contains the baseline wire harness assembly of interest contains approximately 1000 wire harnesses or cables at a weight of 5685 pounds. The 5685 pounds of harnesses or cables has been categorized as follows:

a.	Power distribution systems -	2,929 pounds
b.	Flight essential systems	262 pounds
c.	Mission essential systems	2,358 pounds
d.	Instruments	136 pounds
	Total	5,685 pounds

For comparison and estimation purposes assume use of fiber optics harnesses/cables for all applications except power distribution. Further assume that a weight saving equivalent to the subject fiber optics harness replacement for the baseline wire harness is achieved. This would result in a total weight savings of 1,378 pounds per aircraft. This weight savings would most likely be replaced with jet fuel to increase the sortie length by a factor of 1.167 X 10^{-4} hours/lb, a 0.16 hours (9.65 minutes) sortie time length increase. This represents a 2.5% increase in the average sortie length.

Reliability Benefits

Failure rates for the baseline wire harness assembly were calculated from using the MIL-HDBK-217C reliability handbook to yield a $\lambda = 0.273$ failures per 10^6 hours. Failure rates for the equivalent fiber optics harness assembly were likewise calculated using the MIL-HDBK-217C reliability handbook to yield a $\lambda = 0.2722$ failures per 10^6 hours. The major assumptions made relative to the fiber optics calculations include:

a. Connector reliability will be equivalent to wire harness connectors

b. The harness system will incorporate a single opto-electronic isolator (emitter and detector combination)

c. The quality level of the isolator selected will be high (JANTXV)

d. The fiber end connections will be equivalent to a welded wire end connection (this has a lower reliability than a crimped wire connection but higher than a solder connection)

Comparison of the above would yield the conclusion that wire and fiber optic harnesses have essentially the same failure rate.

Maintenance Costs

The following observations of the historical data are significant relative to maintenance and supply considerations. These observations are made with the recognition of equal reliability predictions for fiber optics and wire harnesses in mind.

a. Of 3,481 harness/cable failures only 161 or 4.6% required a removal and replacement.

b. Of 161 harness/cable removals 104 or 64.6% were repairable while 57 or 35.4% were discarded.

c. A minimum of approximately 713 harness/cables are utilized on four military aircraft which are contained in the historical files.

d. Of 3,481 failures only 57 assemblies were nonrepairable or 1.6%.

In view of the relatively low rate of failure of wire harness/cable assemblies and a correspondingly low rate of nonrepairable assemblies, the general spares policy for the E-3A aircraft has not included spare harness/cable assemblies. Spare parts and materials are maintained as standard supply items by the Air Force.

The spares parts and repair material cost estimates are based on the cost formula outlined in NELC Technical report 1982 and the recommended inventory replenishment factor.

$$\begin{aligned} \text{Cost} &= (\text{Inventory replenishment factor}) \\ &\quad \times (\text{Unit production cost}) \\ &\quad \times (\text{Quantity of Equipment}) \\ &= (0.05) \times (\$3{,}619) \times (1) = \$181 \text{ per harness.} \end{aligned}$$

Inventory management costs are likewise estimated based upon the cost formula outlined in NELC Technical report 1982.

$$(\text{Inventory cost management}) =$$

$$(\text{Number of new FSW items})$$

$$\times \left[\frac{(\text{FSN items cost}) + (\text{FSN item recurring cost}) \times \begin{pmatrix}\text{Number of} \\ \text{years per -1} \\ \text{life cycle}\end{pmatrix}}{(\text{Number of years per life cycle})} \right]$$

Inventory Cost Management =

$$(5) \times \left[\frac{(460) + (110) \times (19)}{20} \right] = \$638$$